Final Report

ADDENDUM TO NASA SYNCHRODYNE CONTRACT

No. NGR 03-002-169

Submitted to

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California 94035

ENGINEERING EXPERIMENT STATION
COLLEGE OF ENGINEERING
THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA

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SUBMITTED BY

Engineering Experiment Station
College of Engineering
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Tucson, Arizona 85721

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ABSTRACT

The purpose of this design is to provide Ames Research Center with a research and fabrication facility for monolithic integrated circuits; the integrated circuit laboratory will complement the existing hybrid circuit facility.

To minimize the initial cost of the proposed facility, their existing building is utilized with a minimum number of modifications, and existing equipment is incorporated into the design. For the purpose of purchasing new equipment, a list of recommended equipment is included for all major areas. The design includes the equipment arrangement, building modifications, manpower requirements, and a schedule for laboratory development.

CHAPTER 1

INTEGRATED CIRCUIT LABORATORY DESIGN CONCEPT

The proposed laboratory design will provide the Ames Research Center with a monolithic integrated circuit research and fabrication facility. The processing capability that is essential to the proper operation of the laboratory is shown in the process flow diagram, Fig. 1-1. The laboratory will also utilize a limited amount of support from existing in-house capabilities such as the Glass Fabrication, Vacuum, Microphotography, and Hybrid Circuits facilities. The integrated circuit laboratory is to be parallel to the existing hybrid circuit facility. This approach will provide optimum use of available resources.

As a result of our evaluation of the building and available floor space for an integrated circuit laboratory, the following recommendations are made. Room 215 is to be used for circuit testing, encapsulation, mask generation and artwork generation. Room 215B is to be used for photo engraving, oxidation and diffusion, and general chemical preparation. Room 216 is to be used for metallization and the deionized water system. Figure 1-2 shows the general space allocations and the changes in room dimensions. The details of equipment and building modifications will be given in the subsequent chapters.

The criteria used in the design of the integrated circuit laboratory are the optimum uses of capital investiment and manpower to result in a flexible and useable laboratory. Each of the major areas

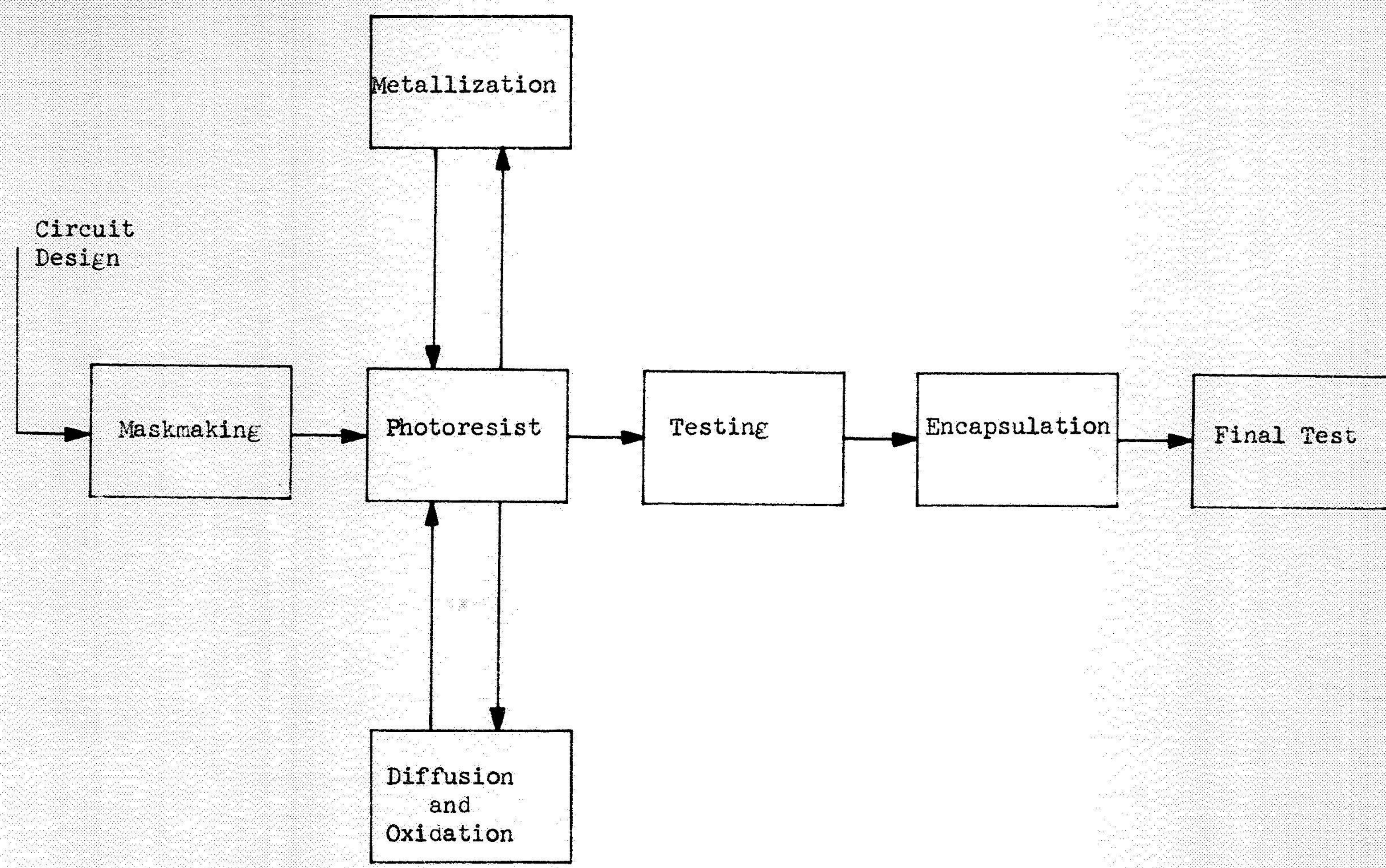

Figure 1-1 Process Flow Diagram for the Proposed Integrated Circuit Laboratory

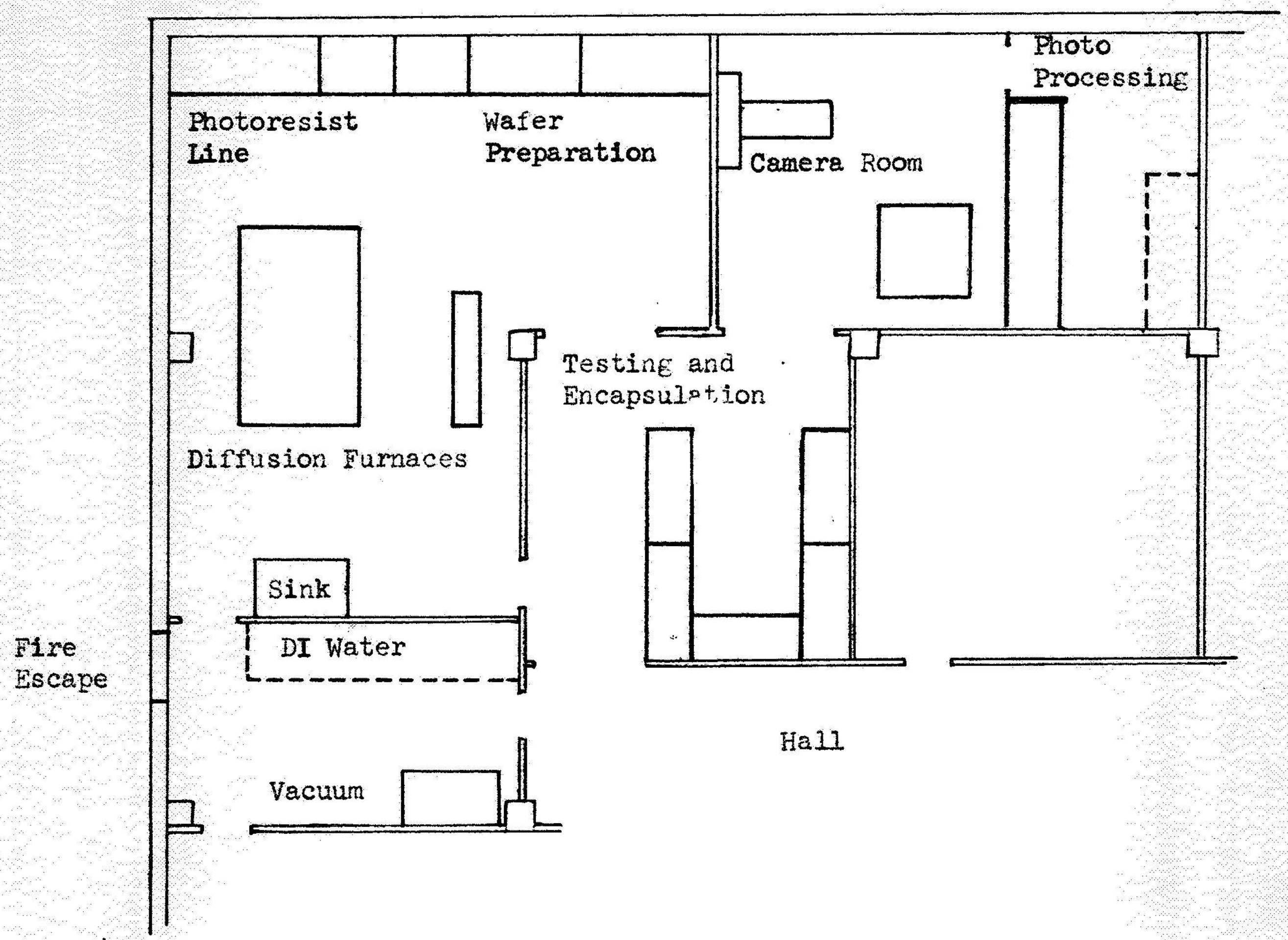

Figure 1-2 Allocation of Floor Space

are evaluated separately, and the evaluation contains a general review of the processes involved, equipment recommendations, equipment location, and necessary building modifications. In the selection of equipment, the equipment will be evaluated with respect to its functional criteria, ease of operation, reliability, and cost.

Chapter 6 is a review of special problem areas and building modifications. Chapter 7 is a summary of the entire laboratory design.

CHAPTER 2

ARTWORK AND PHOTOMASK GENERATION

2.1 General Maskmaking Systems

The systems presently available for photomask generation vary in complexity from the simple fly's eye camera system to systems utilizing computer aided design. For the maskmaking facilities at the Ames Research Center, the three methods that will be considered are mask generation by an outside company, mask generation by a fly's eye camera, and mask generation by a step and repeat camera. These methods offer the most feasible methods of mask generation for the size of the laboratory. There are systems of greater complexity available, but their cost is considered prohibitive. Figure 2-1 is a flow diagram of the three basic systems.

Throughout the entire process of mask generation, it is necessary to insure that the dimensional errors do not exceed the maximum tolerances allowed in the final image. The three major sources of error are original artwork, image reduction, and step and repeat error. Common to all three systems is the generation of artwork. After a circuit has been designed and the geometrical circuit design laid out, the artwork is cut on a coordinatograph and used as the initial pattern for the mask generation.

The evaluation of equipment used in mask generation is based on the analysis of errors given in Appendix A.

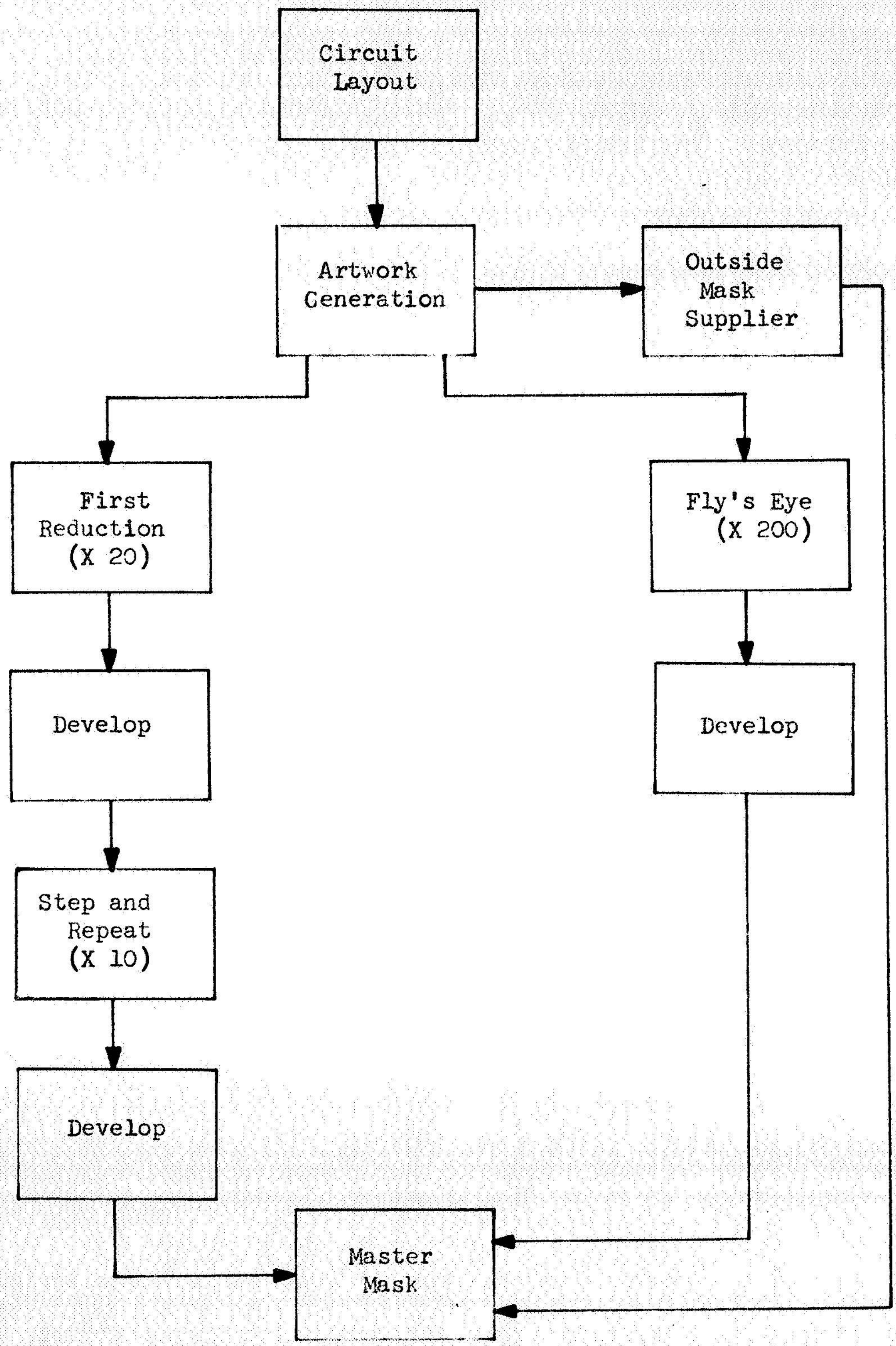

Figure 2-1 Maskmaking Flow Chart

A coordinatograph consists of an ultra-flat light table and precision x and y coordinate arms for measurements and cutting. The following is a list of the criteria that is considered necessary for a coordinatograph.

1. Positioning accuracy: $\pm$ 0.001 inch
2. x and y coordinate range: 32 inches
3. ultra-flat light table
4. air cooled table
5. fluorescent light
6. English unit scales
7. pricker microscope
8. precision cutting attachment

Artwork may also be produced by using a light table and drafting machine. This method does not minimize the amount of artwork error, but it is possible to generate acceptable artwork when the final minimum linewidth desired is one mil or larger. Purchasing this system would save $5,739.00 when compared with the cost of a coordinatograph.

The artwork must be photographically reduced in one or more steps and repeated into an array to provide masks for the fabrication of integrated circuits. Figure 2-2 is a drawing of a typical reduction camera with the major parts of the camera noted on the drawing. [Schwartz, 1967, pp. 67-68]

A reduction camera must have the following physical requirements:

1. free from vibration

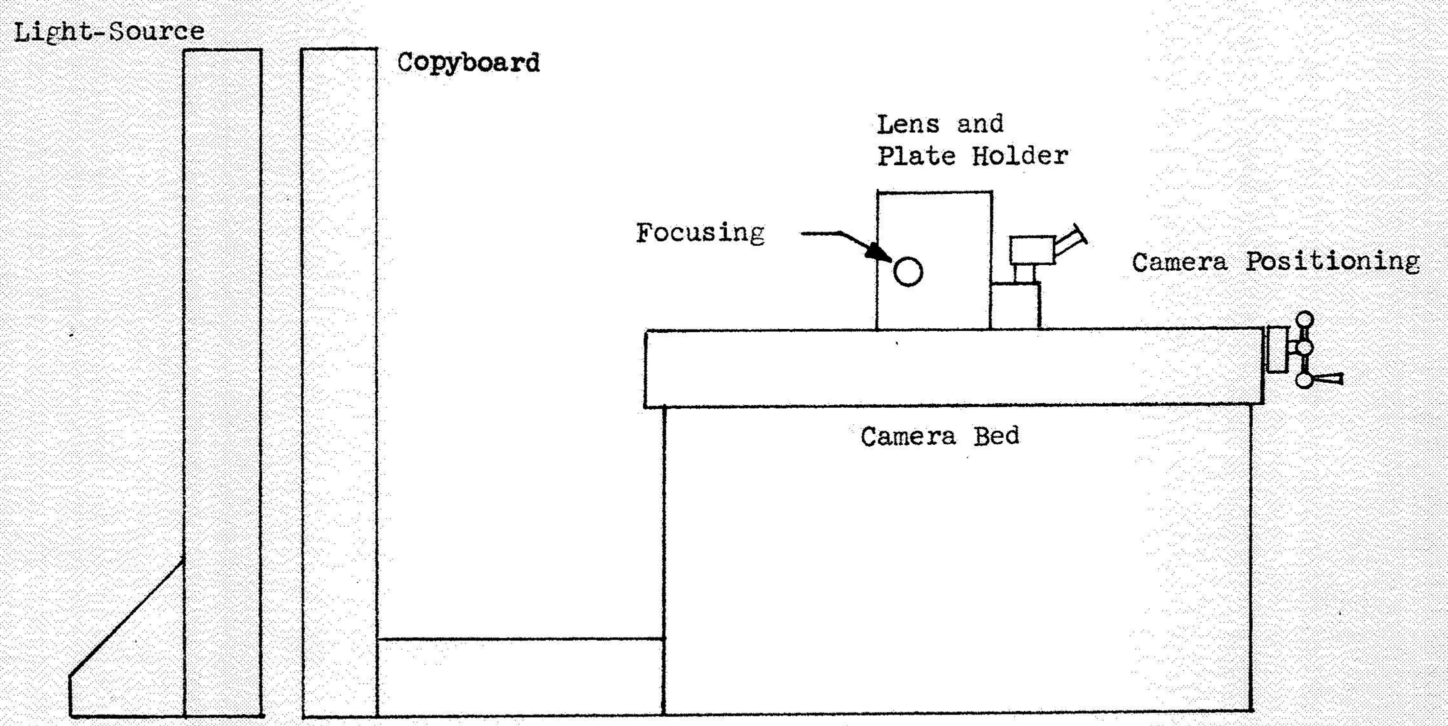

Figure 2-2 Reduction Camera

2. accurate positioning device
3. accurate focusing device
4. monochromatic light source
5. high resolution, low distortion lens
6. suitable range of reduction ratios
7. shutter control and timing device
8. accurate camera alignment

The existing reduction cameras at Ames Research Center do not meet these specifications. The cameras lack the ability to be precisely located. This results in the lack of repeatability within the allowable range of error. Furthermore, the lenses on the existing cameras do not have the resolution necessary for final image reductions. The Borrowdale camera lacks stability. Although stabilizing bars could be purchased for this camera, the amount of vibration inherent in the camera is not acceptable for integrated circuits work. The previous reduction work performed by the staff of the photographic section was excellent but it is an indication of the absolute maximum capability of the system. This work would be very difficult to duplicate on the daily basis needed for integrated circuits work, and the time and manhours needed to perform the work would be prohibitive. Thus, it is concluded that a camera system for integrated circuits work must be purchased.

In order to produce an array of identical images, it is necessary to have a step and repeat camera. There are two major types of step and repeat cameras. The fly's eye consists of a multiple array of lenses. Figure 2-3 shows the typical arrangement of a fly's eye system.

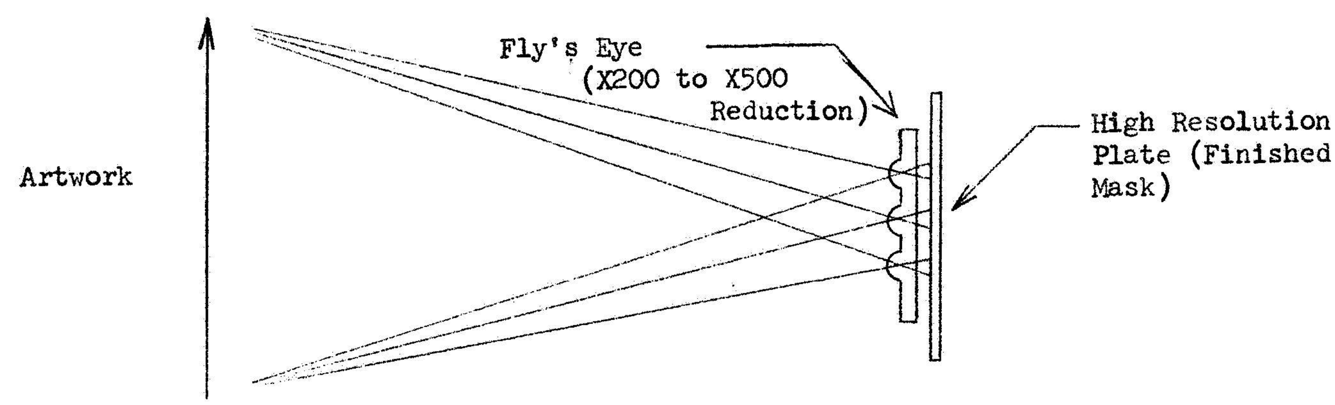

Figure 2-3 Fly's Eye System

The fly's eye camera requires only one photographic step from the artwork to the finished mask. The reduction ratio ranges between 200 to 500 times. The fly's eye system provides a standard chip size that is limited by the size of the individual lens in the array. The second method of step and repeat consists of an optical system and a precision stepping frame. There are several combinations of optical systems and stepping frames presently used in the generation of masks. The stepped image is either stepped at the final reduction size or at an intermediate reduction size and then reduced to the final image size. [Schwartz, 1967, p. 69]

The physical requirements for a step and repeat camera are:

1. accurate stepping frame
2. high resolution optical system
3. monochromatic light source
4. exposure control
5. rigid construction
6. vibration free
7. accurate focusing

2.2 Equipment Evaluation and Recommendations

2.2.1 Camera Systems

The comparison of the available reduction cameras, step and repeat cameras, and the possible combinations of these camera systems is given in Appendix B. The David Mann system provides semi-automatic step and repeat operation, 1/10 mil geometry capability, and the lowest degree of error.

Fly's eye camera systems are presently available in a price range between $16,000.00 and $20,000.00. It is possible for Ames Research Center to construct its own fly's eye camera system for less than $10,000.00. Appendix C is an initial engineering evaluation of a possible fly's eye camera system.

2.2.2 System Recommendations

There are three mask generation systems considered to be feasible for the integated circuit laboratory. The first system is to cut the artwork for the masks, and then have the masks produced by a commercial company. A set of five masks for one device would cost approximately $490.00. (See Appendix D for cost analysis.) The only required equipment would be a coordinatograph for cutting the artwork. The second system is the David Mann Camera system. The recommended equipment for the David Mann System is given in the recommended equipment list at the end of this chapter. This system would produce a set of five masks for approximately $110.00. However, the initial investment of $52,660.00 would require 123 sets of masks before the masks produced on the David Mann system would cost less than having the masks produced by an outside firm. The third system is the fly's eye camera. The fly's eye system would produce a set of five masks for $77.50.

Figure 2-4 shows the cost analysis of the three systems. The fly's eye system combined with a commercial mask source will provide the most economical means of mask generation. For general research and evaluation work, the fly's eye camera will provide inexpensive masks in the shortest possible time, and it will minimize circuit redesign cost.

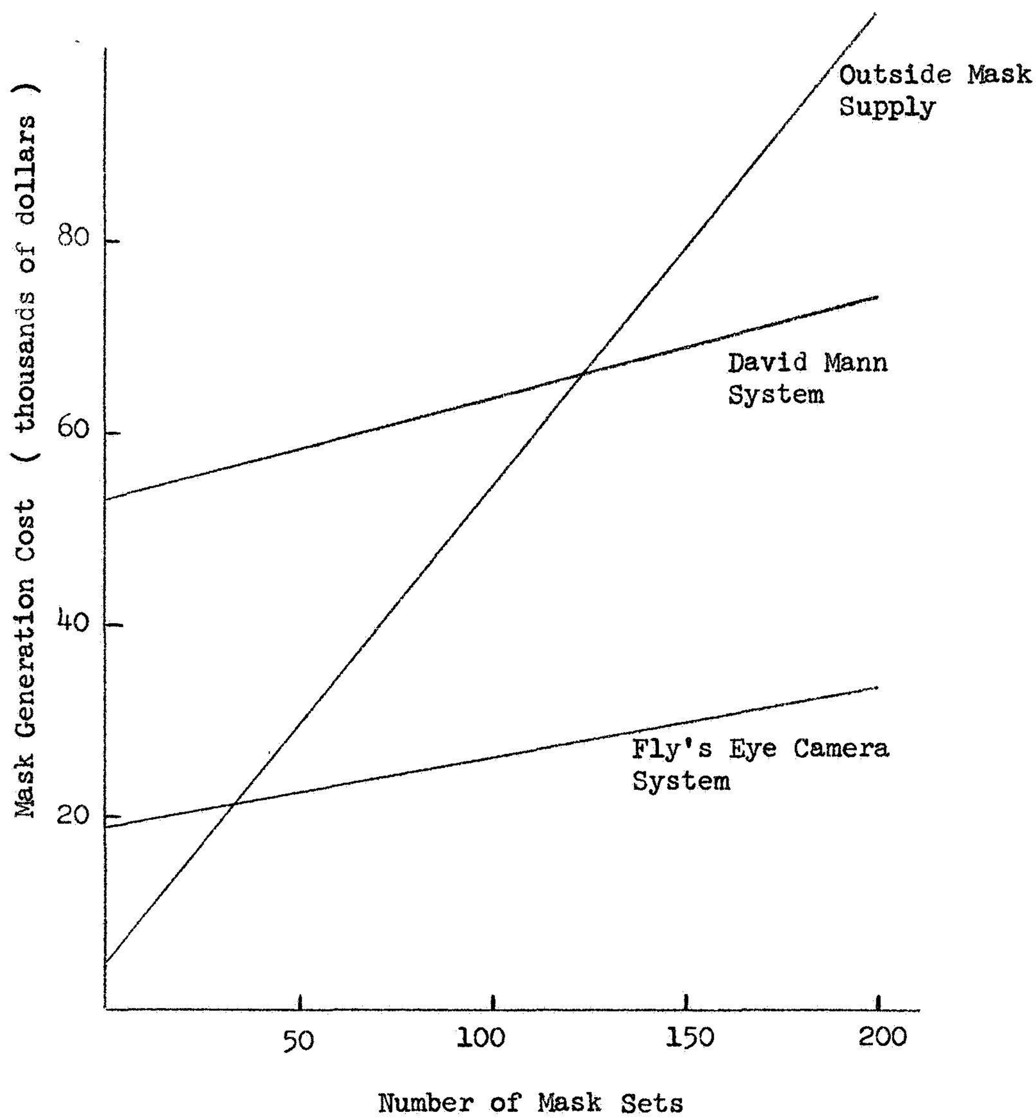

Figure 2-4 Mask Generation Cost

If an integrated circuit were desired in large quantities, the artwork could be sent to a commercial source. The masks would be guaranteed to the specified tolerances and working masks could be purchased for $10.00 or less depending upon the quantity ordered.

The David Mann system would be the most versatile in-house mask generation system.

As the integrated circuit laboratory becomes operational, other systems may become desirable such as computer aided design and automatic artwork generation. Therefore, it may be desirable to purchase an inexpensive system until the future requirements for circuit design and fabrication can be more fully evaluated.

2.3 Photo Processing System

A photographic processing area is needed for developing high resolution plates used in mask generation. Figure 2-5 shows the standard processing steps used in developing high resolution plates. In processing the plates, the following items are considered critical:

1. processing temperature control
2. processing cycle time
3. high purity water
4. contamination control

Figure 2-6 shows the general layout of the mask generation and and processing area. Figure 2-7 and 2-8 show the processing area required to develop the high resolution plates.

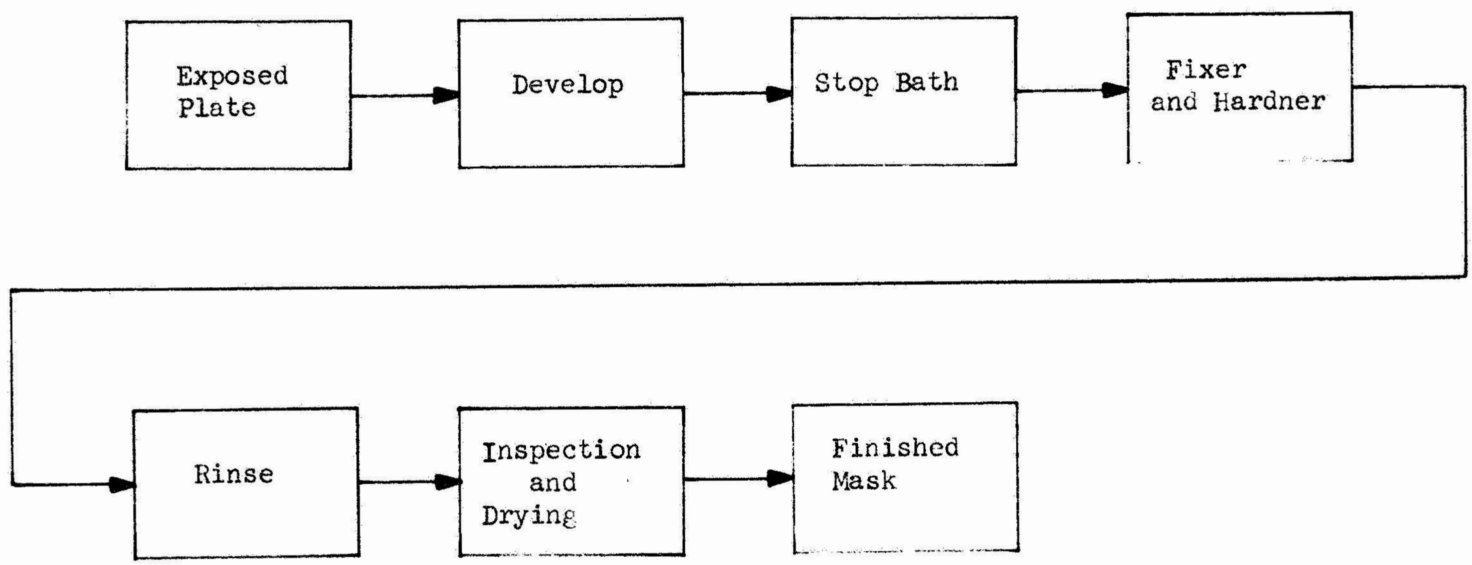

Figure 2-5 Developing Process for High Resolution Masks

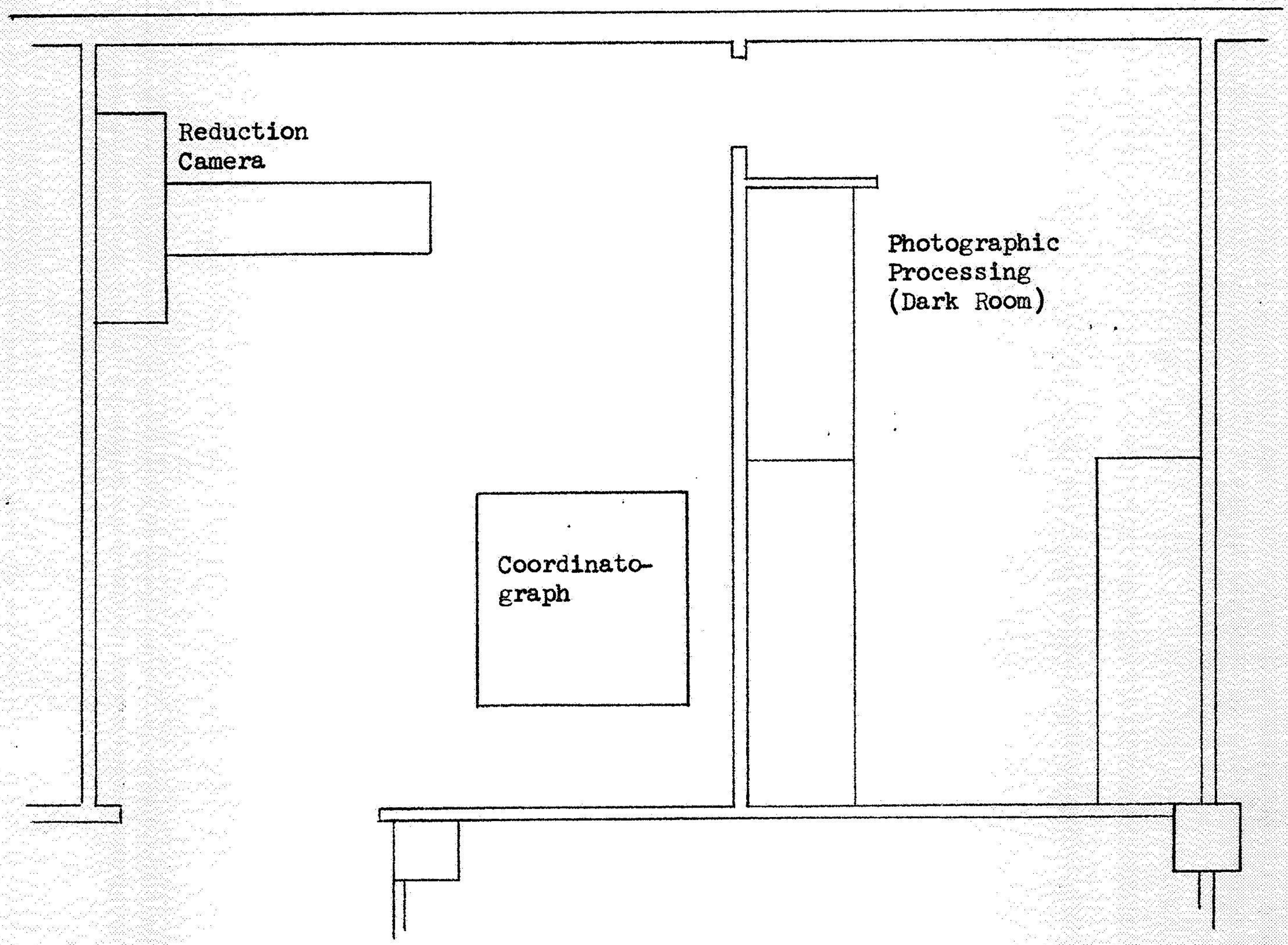

Figure 2-6 Mask Generation Area

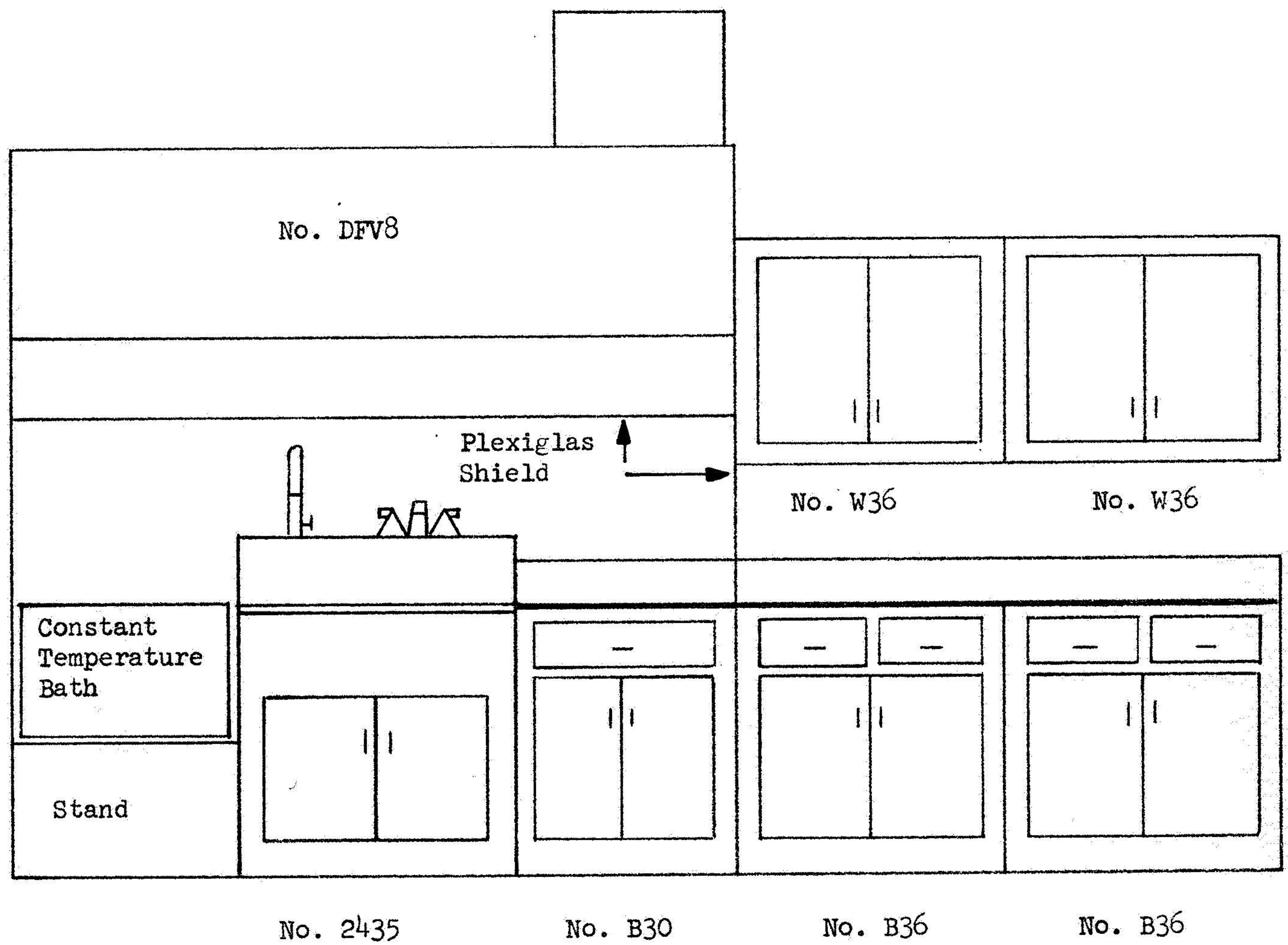

Figure 2-7 Photographic Process Area

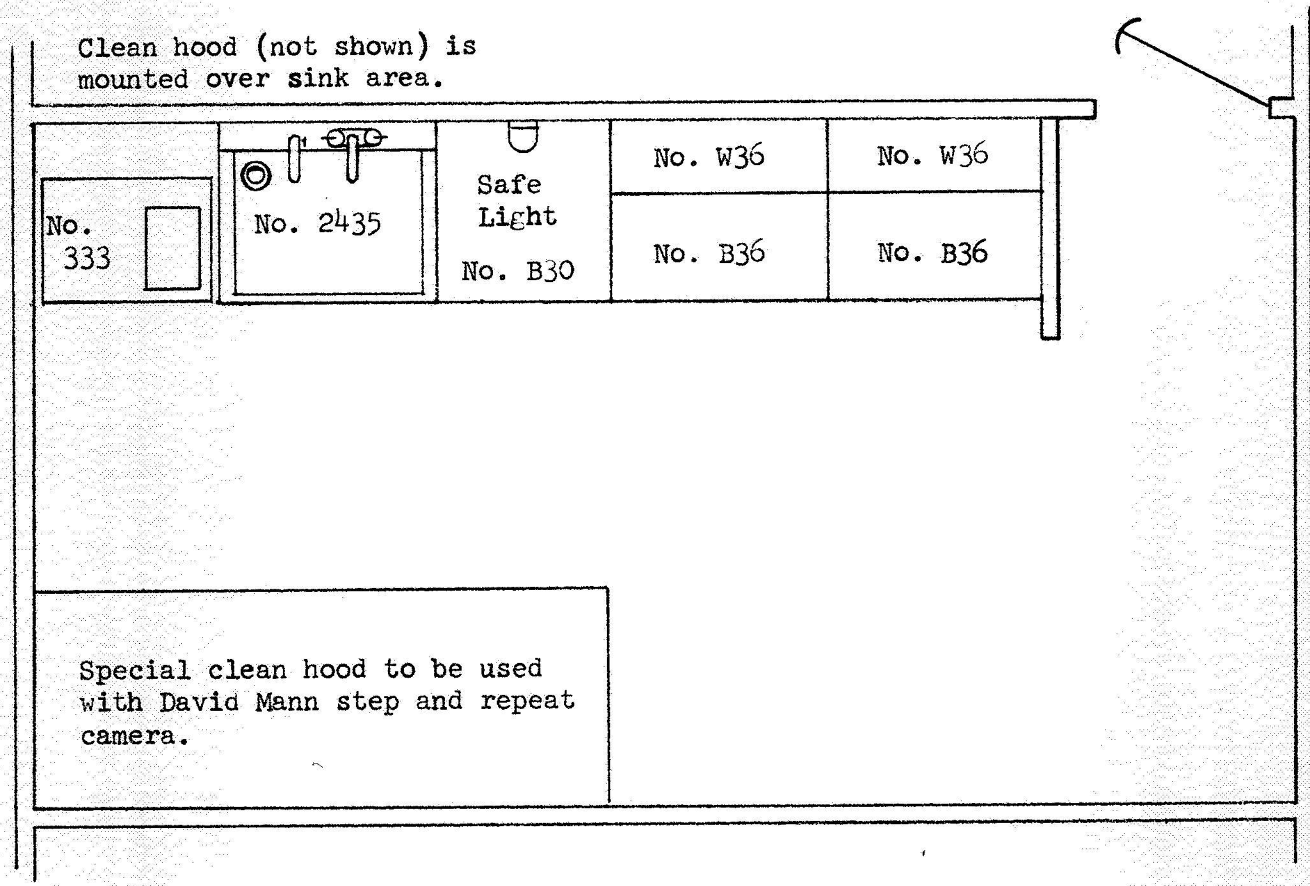

Figure 2-8 Layout of Photo Processing Room

2.4 Coordinatograph

The recommended coordinatograph and accessories are listed in the Recommended Equipment list. The comparison of coordinatographs is given in Appendix B.

RECOMMENDED EQUIPMENT

Processing

Description	Number Required	Price
Processing Area, Kreonite Co.		
Tray Processing Sink, Model No. 2435	1	$ 400.00
Base Cabinet, Model No. B30	1	167.00
Base Cabinet, Model No. B36	2	416.00
Wall Mount Cabinets	2	236.00
Faucet, Model No. KF230S	1	54.00
Base Cabinet Tops		153.00
		$ 1,426.00
Constant Temperature Refrigerated Bath, Hotpack, Model No. 333		$ 550.00
Vertical Laminar Air Flow Unit, Agnew-Higgins, Model DFV8		895.00
Mounting and Plexiglas for Agnew-Higgins, Model DFV8 (est)		200.00
		$ 1,645.00
TOTAL		$ 3,071.00

Description	Number Required	Price
Coordinatograph, Faul Inc., Model No. KDB 1083	1	$ 5,739.00
Fly's Eye System		$ 10,000.00
David Mann System		
Step-and-Repeat, Model 1480	1	$ 25,000.00
Master Reticle Alignment, Model 1492		3,100.00
Reduction Camera, Model 1503		13,900.00
		$ 42,000.00
Vacuum Pump, Gast Vacuum Co. Model No. 1550		$ 350.00
Laminar Air Flow and Table, Agnew-Higgins Inc. (Special Design)		1,500.00
		$ 43,850.00

Mask Making Systems

1. Outside Source	$ 5,739.00
2. David Mann System	$ 52,560.00
3. Fly's Eye System	$ 18,610.00

CHAPTER 3

PHOTORESIST AND DIFFUSION

3.1 Wafer Preparation

Wafer preparation in the integrated circuit laboratory will be mainly the precleaning of wafers before processing. Due to the high cost of equipment and manpower and the relatively low cost of silicon wafers, no provision has been made for the polishing of silicon wafers; silicon wafers should be obtained from an outside supply source. The area that is to be used for precleaning wafers and general chemical preparation is shown in Fig. 3-1. The wafer preparation area consists of the following equipment:

1. fume hood
2. sink
3. cabinets with chemical resistant tops
4. wall mounted storage area
5. storage cabinets

The wafer preparation area provides storage space for supplies and laboratory equipment. The fume hood provides a place for wafer cleaning and chemical preparations with maximum safety for technicians. The counter area to the right of the fume hood provides room for wafer inspection and wafer testing. An additional cleaning sink will be located in the load station of the diffusion furnaces.

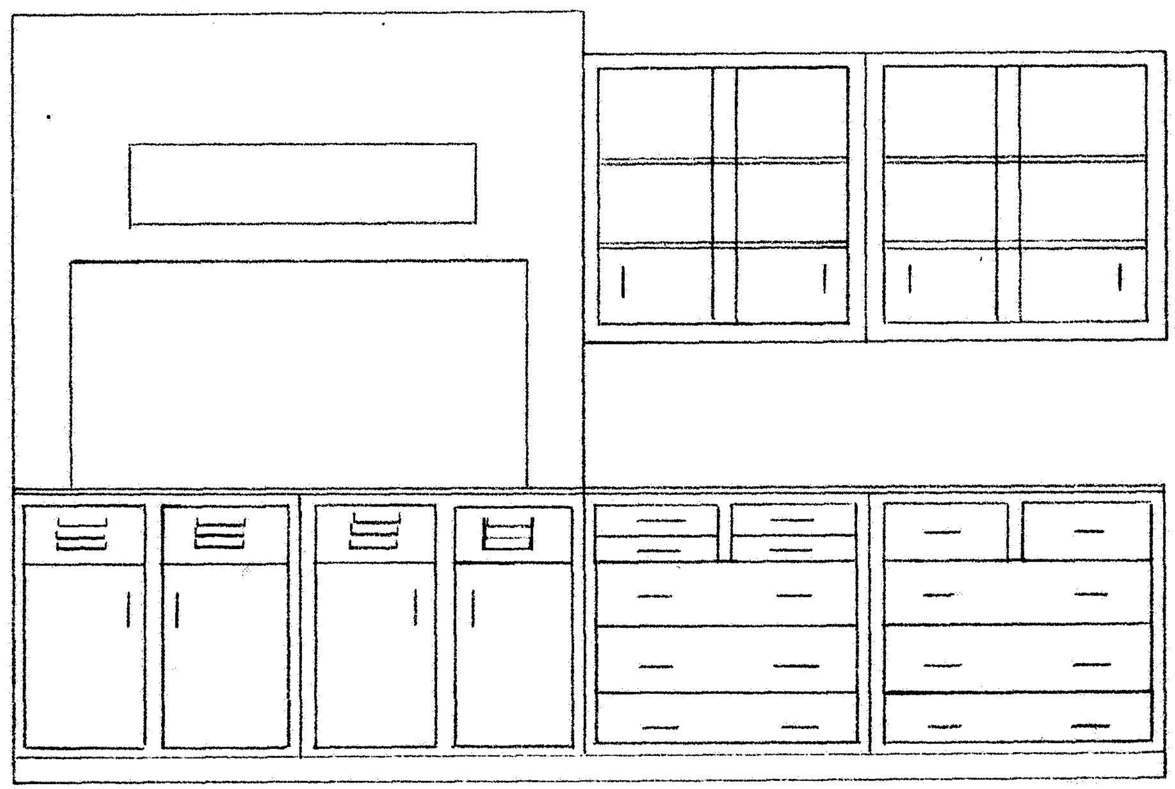

Figure 3-1 Wafer Cleaning and Measurement Area

3.2 Epitaxial

All epitaxial work is to be performed by outside sources. Due to the high cost of epitaxial equipment and the large amount of manpower to develop the epitaxial capability and processes, it is more economical to have the work performed by an outside source.

3.3 Integration of Diffusion and Photoresist Areas

The diffusion furnaces and the photoresist line have been placed opposite each other to provide optimum utilization of floor space and manpower. The photoresist line and diffusion furnaces are separated by a distance of seven feet. This will allow one or more technicians to process wafers through the photoresist line and through the diffusion furnaces with a minimum number of steps. This configuration reduces the amount of building modification necessary for the two areas.

The photoresist line and the furnace load station are laminar air flow units. The opposing laminar air flow hoods produce an area of positive air pressure between the diffusion furnaces and the photoresist line. The positive air pressure reduces the amount of contamination between the two lines. [Agnew, 1965, p. 12] The combining of the diffusion and photoresist areas makes it feasible to use a single polishing unit for the deionized water which will provide the photoresist line, the wafer cleaning sink, and the load station sink with 15 to 18 megohm water.

3.4 Photoresist Line

Figure 3-2 is a flow process diagram for the photoresist line. The process line is adaptable to all major photoresists currently in

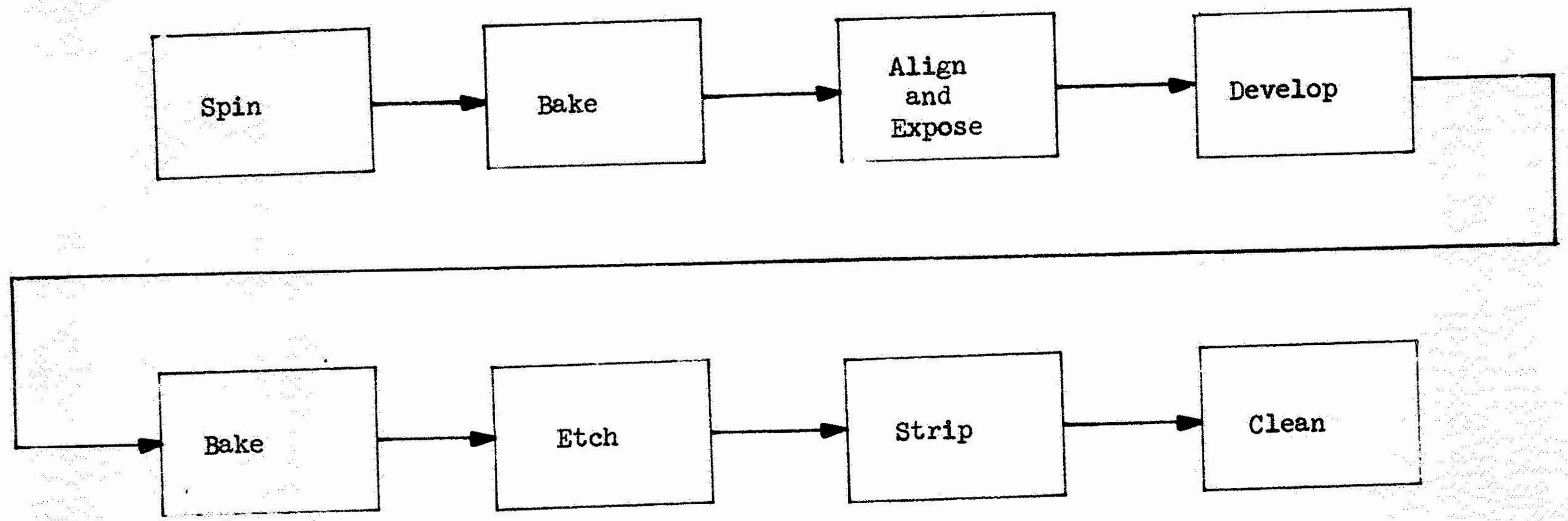

Figure 3-2 Photoresist Process Flow Diagram

use. The photoresist line is completely enclosed in laminar air flow which provides contamination control for processing. Figures 3-3 and 3-4 show the proposed photoresist line.

The following equipment is necessary for the photoresist line:

1. laminar air flow clean hood
2. laminar air flow exhaust hoods
3. etch and develop sinks
4. photoresist spinner
5. mask alignment unit
6. bake ovens
7. hot plates
8. centrifuge

The photoresist spinner is a Plat model No. 102 which is currently available at Ames Research Center for the photoresist line.

The alignment fixture is a split field electro-glass alignment unit, Model No. 360. The comparison of the various alignment fixtures is given in Appendix B.

A centrifuge is included for precleaning photoresist before application.

3.5 Diffusion and Oxidation Furnaces

The diffusion system for the integrated circuit laboratory is designed for gaseous sources; however, the system is easily adaptable to liquid sources. The gas sources will provide maximum process control and process repeatability. The system requires eight diffusion chambers, two for oxidation, three for doping and three for drive-in. The

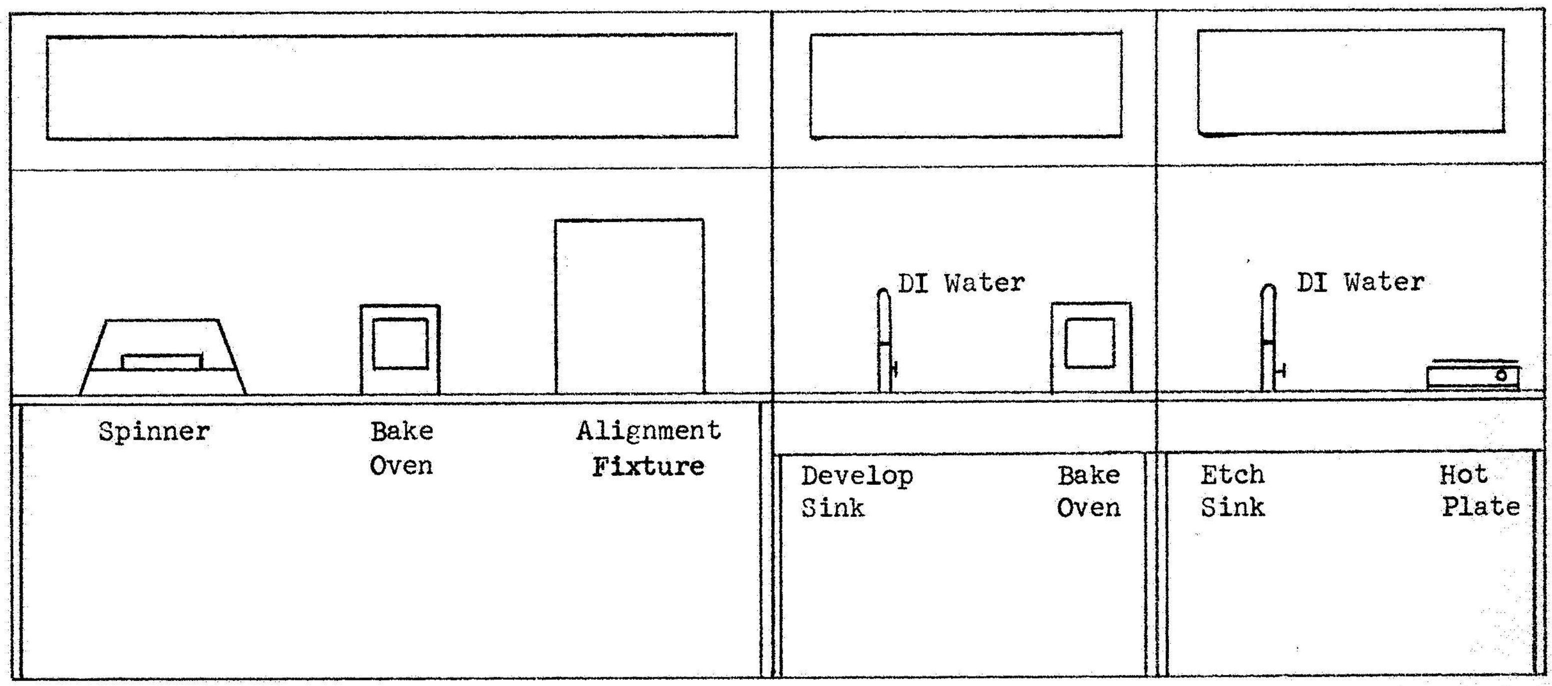

Figure 3-3 Photoresist Line

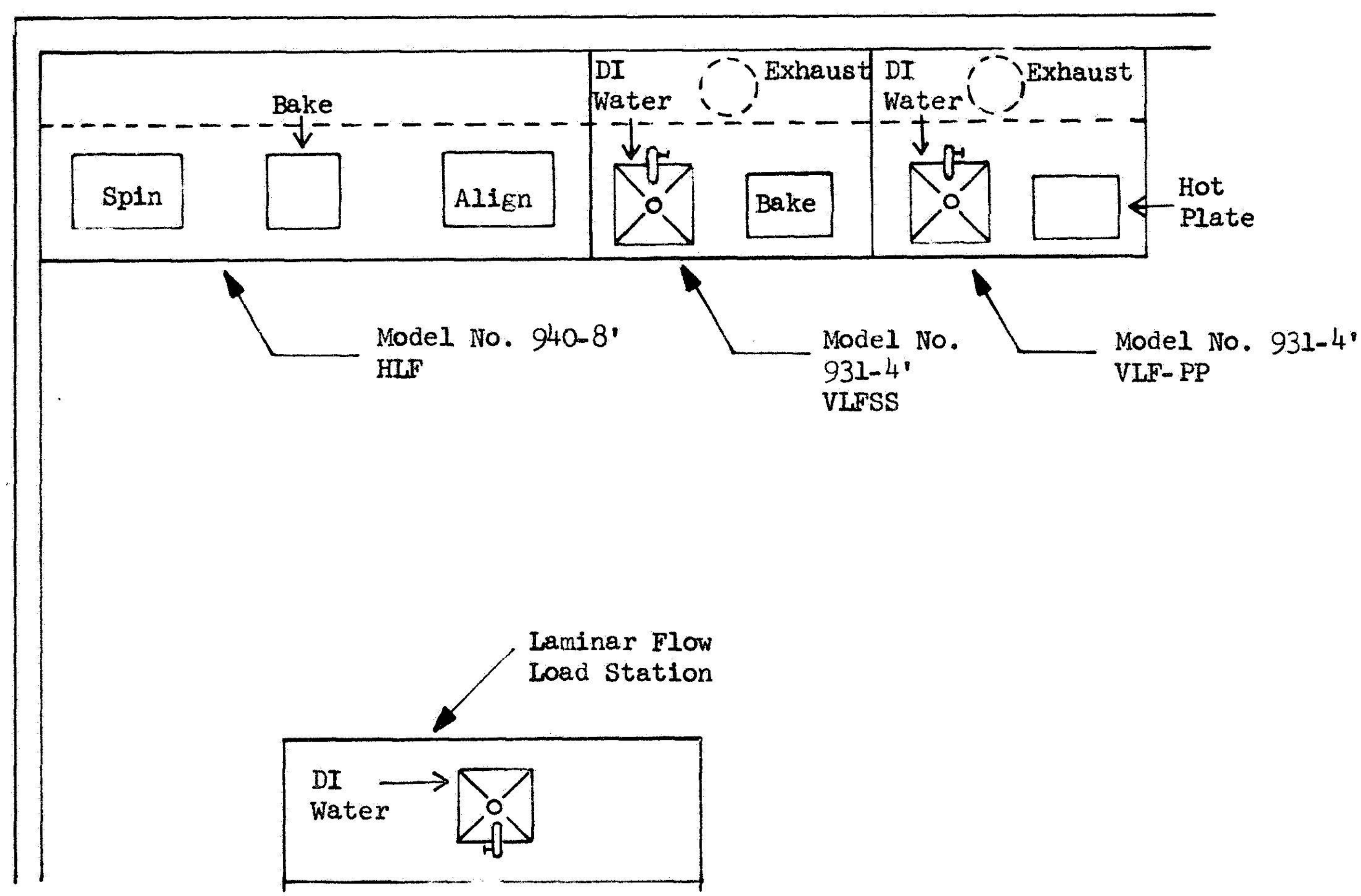

Figure 3-4 Floor Layout of Photoresist Line

oxidation tubes provide oxidation by either steam or dry oxygen. The doping gases are diborane, phosphine and arsine. [Smith, 1964b]

The major criteria on which the furnaces are judged are the temperature characteristics. The profile of each diffusion chamber must have a flat zone in which the temperature variation is not greater than $\pm \frac{1}{2}{}^{o}C$. The temperature profile must also remain stable over a long period of time. The two temperature control systems used in diffusion furnaces are the master slave controller and single point proportioning controller. The master slave controller provides better temperature control and a flatter temperature profile. [Schwartz, 1967, pp. 19 - 23]

The barrel arrangement is shown in Fig. 3-5. A laminar air flow hood is placed across the front of both three-chamber diffusion furnaces. The majority of all processing will be performed with these six diffusion chambers. The laminar flow hood will minimize wafer contamination. A sink is located in the load station with deionized water. At the rear of each stack of diffusion chambers is a gas control cabinet. This cabinet contains the gas control panels, the doping gases, the doping gas manifolds and regulators, the doping gas purge systems, and gas line regulators.

The chamber diameter should not be less than three inches. The Over Temperature Control units prevents thermal run away destruction of furnace elements. Push rod and thermocouple holders are located in the load station.

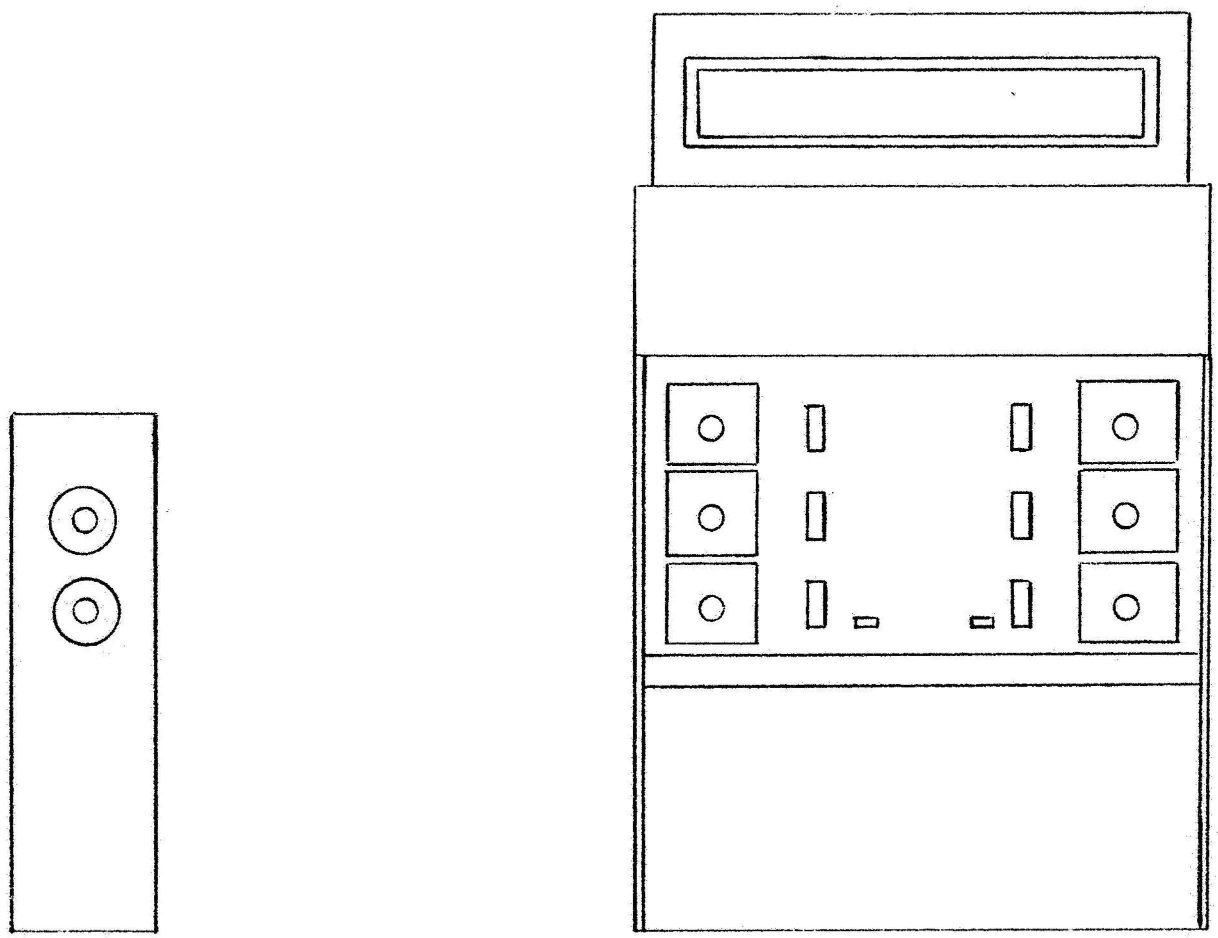

Figure 3-5 Barrel Arrangement

The evaluation of the various available furnaces is given in Appendix B. The recommended furnaces and optional equipment is listed at the end of this chapter in the Recommended Equipment list.

3.6 Furnace Layout and Configuration

Additional information on the required power, exhaust, chilled water, deionized water, drains and gas lines is given in Chapter 6.

A gas control system is needed to control processing characteristics. The configurations for the gas control systems are shown in Figs. 3-6 and 3-7. The gas control system for the diffusion tubes requires four flow meters and eight toggle valves per panel. The gases from the control panels are then fed into mixing manifolds and then into the diffusion tubes. The gas control panels for the oxidation and drive-in furnaces require three flow meters and six toggle valves per panel. The gas flow from the nitrogen and one oxygen flow meter are fed into the mixing manifold. The oxygen from the second oxygen flow meter is fed into a temperature controlled flask of water. The oxygen is bubbled through the high purity water, and the mixture of oxygen and steam is fed into the gas line between the mixing manifold and quartz tube.

The gas supply lines coming from the gas storage area will have a gas pressure of 35 psig. Each gas control cabinet will have a line regulator and gauge. From the regulator the gas will be fed to each of the gas control panels.

The doping gas supply configuration is given in Fig. 3-8. The doping gas supplies are located in the lower portion of the gas control

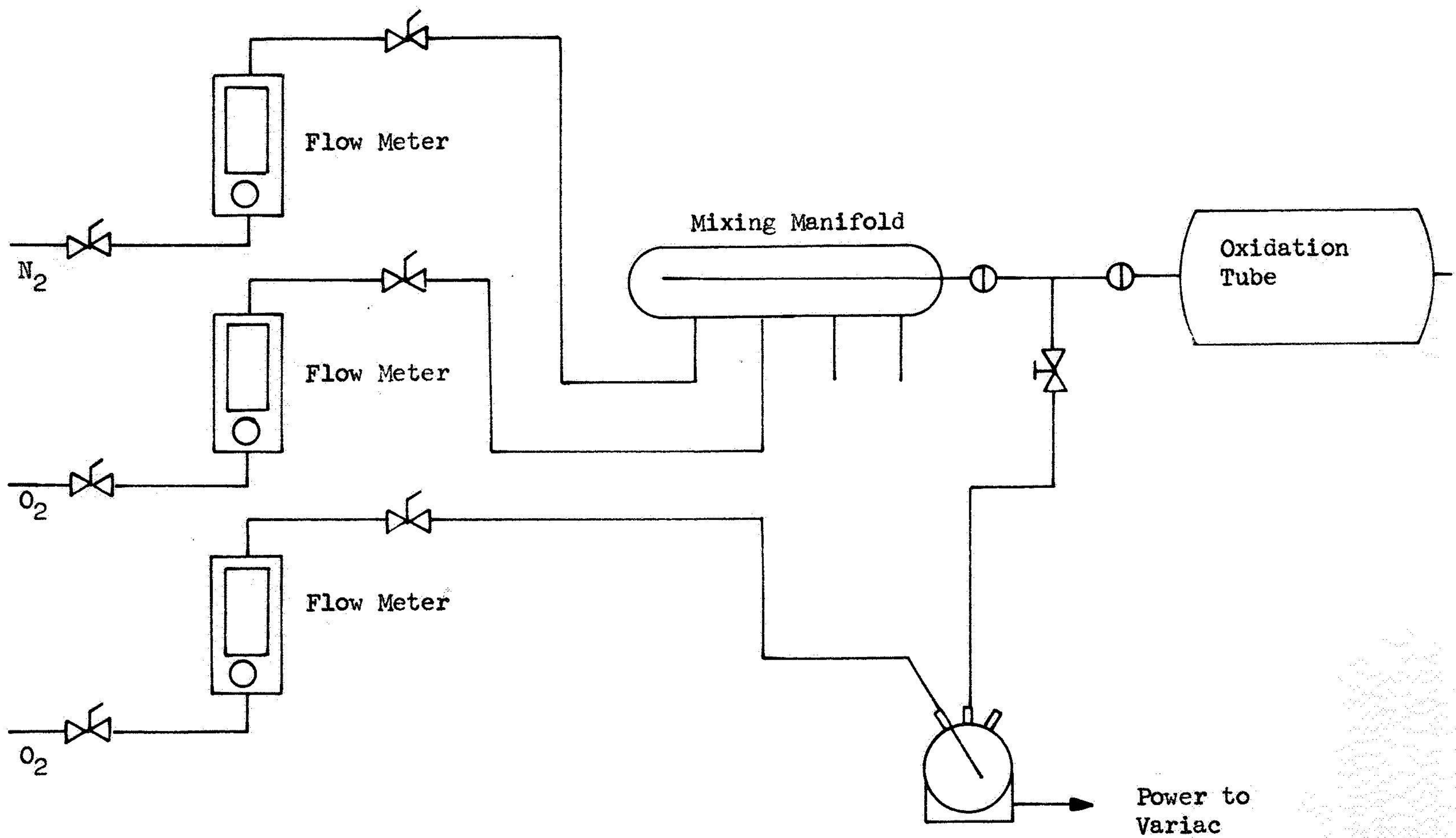

Figure 3-6 Gas Control System for Oxidation and Drive-in

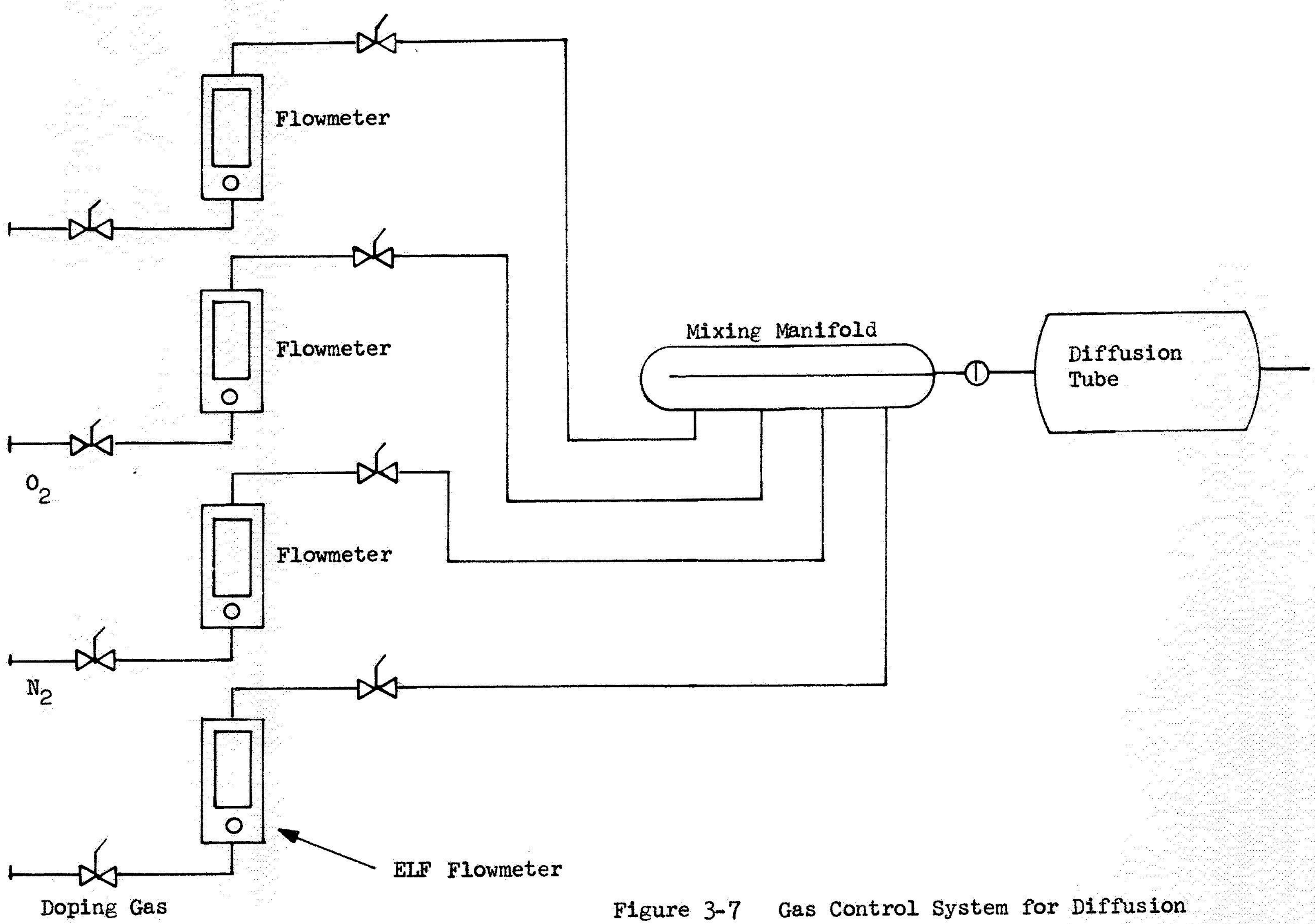

Figure 3-7 Gas Control System for Diffusion

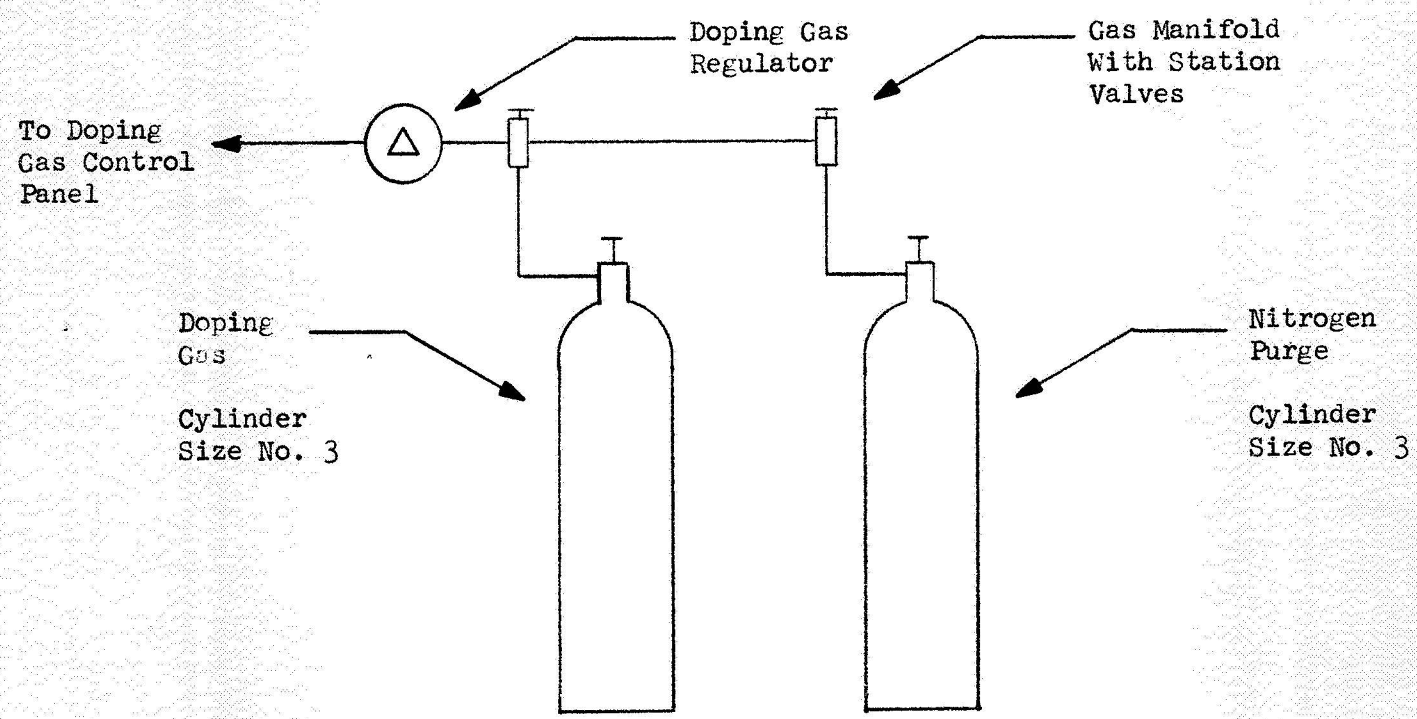

Figure 3-8 Doping Gas Supply Configuration

cabinets. The doping gas system consists of a doping gas supply tank, nitrogen purged tank, manifold, and regulator.

3.7 Glassware

The following glassware will be needed for the furnace system:

1. mixing manifolds
2. quartz tubes
3. end caps
4. steam oxidation system
5. push rods
6. boats

The glassware may be all or partly fabricated by the Ames Research Center glass facility; however, local glass companies may be able to supply the required glassware for less than the in-house fabrication cost. The steam oxidation system is also available in modular form. To insure that the temperature profile is maintained, a means of recording the profile is needed. Automatic profilers are available, but the profile may be recorded manually with a shielded thermocouple and a precision potentiometer.

RECOMMENDED EQUIPMENT

Wafer Preparation Area

Description	Number Required	Price
Van Waters and Rodgers, Inc. Catalog No. 96		
Fume Hood, Catalog No. 30176-061	1	$ 845.00
Base Cabinets, Catalog No. DB 35-H	2	163.00
Sink, Catalog No. 7020	1	70.50
Base Cabinets, Catalog No. DR 35-H	2	300.00
Wall Cabinets, Catalog No. 1754	2	183.00
Counter Tops, Vanrock, Style C, for base cabinets, No. DB 35-H	2	92.40
Counter Top, Vanrock, Style D, for base cabinets, No. DR 35-H	2	111.30
High Cabinets, Catalog No. 1790	2	570.00
Sink Cutout	1	12.00
TOTAL		$ 2,347.20

Photoresist Line

Description	Number Required	Price
Clean Work Stations, Contamination Control Inc.		
Model No. 931-4' VLF-PP	1	$ 1,725.00
Model No. 931-4' VLF-SS	1	1,750.00
Model No. 940-8' HLF	1	1,615.00
PVC Gooseneck Faucet With Valve	2	80.00
Pass Throughs, Sliding Door	2	70.00
		$ 5,240.00
Mask Alignment System Electroglas, Inc., Model No. 360	1	$ 5,836.00
Bake oven, Blue M, Model No. 5010	2	$ 238.00
Hot Plate: Van Waters and Rodgers Catalog No. 33976-009	5	138.00
Ultrasonic Cleaners, Cole-Parmer Instrument Co., Model No. 8845-4	2	200.00
Centrifuge, International Model HT	1	870.00
Chair, Dependable Manuf. Co., Model No. 1917	1	62.00
Timers, Cole-Parmer, Model No. 8620	3	87.00
		$ 1,595.00
Photoresist Line, TOTAL		$ 12,671.00

Diffusion Area

Description	Number Required	Price
Furnaces, Thermco Products		
Thermo "Spartan" Model, double chamber diffusion furnace, type 200. Specification No. 501681	1	$ 5,575.00
Water Cooling System	1	250.00
Stainless Steel Toxic Scavengers	2	170.00
Special Base Cabinet 18" X 30"	1	375.00
		$ 6,370.00
Thermco "Spartan" Model, triple chamber diffusion furnace, type 300	2	$ 16,050.00
Water Cooling System	2	500.00
Stainless Steel Toxic Scavenger		510.00
Thermco Vertical Laminar Flow Load Station, 6 ft. nominal	1	1,800.00
Triple Chanber Source Cabinet	2	1,080.00
		$ 19,940.00
Excess Temperature Control	8	$ 1,400.00
Thermocouple and Pull Rod Storage Tubes	6	510.00
Deplex 115 Volts Receptacles	2	64.00
Load Station Sink (est.)	1	150.00
		2,124.00
TOTAL		$ 28,434.00

Description	Number Required	Price
Glassware		
Quartz Tubes	8	$ 848.00
End Caps	8	65.00
Mixing Manifolds	8	200.00
Boats	8	120.00
Push Rods	8	8.00
		$ 1,241.00
Additional Equipment		
Potentiometer, Leeds and Northrup, Model No. 8686	1	$ 485.00
Microscope, Unitron, Model PL-MEC	1	468.00
Rear Lab Sink, Van Waters and Rogers, Model No. 7092	1	345.00
Copper Tubing, 400 feet		52.00
Fittings, $\frac{1}{4}$" Swagelok		200.00
		$ 1,550.00
Steam Oxidation System		
Flask, 1000 ml	1	$ 8.00
Heating Mantle	1	17.50
Transformer, Variable	1	27.00
Glass Fittings and Fabrication		30.00
Cost Per Oxidation System		$ 82.50

Description	Number Required	Price
Steam Oxidation System	4	$ 330.00
Oxidation and Drive-in Gas Control Panels		
Flowmeter, Brooks, Model No. 1355 With needle control valve, brass end fittings and $\frac{1}{4}$" Swagelok connections	3	$ 147.00
Toggle Valves, Whitey, No. 1 series Part No. 1GS4	6	42.20
Panel, (est.)	1	30.00
Cost Per Panel		$ 217.20
Drive-in and Oxidation Gas Control Panel	5	$ 1,086.00
Doping Gas Control Panels		
Flowmeter, Brooks, Model No. 1355 With needle control valve, brass end fittings, and $\frac{1}{4}$" Swagelok connections	3	$ 147.00
Flowmeter, Brooks, Model No. 1355-8505, with ELF needle valve, brass end fitting, and $\frac{1}{4}$" Swagelok connections	1	63.30
Toggle Valve, Whitey, No. 1 Series, Part No. 1GS4	8	53.60
Panel (est.)	1	30.00
Cost Per Panel		$ 293.90
Doping Gas Control Panels	3	$ 882.00

Description	Number Required	Price
Doping Gas Manifold System	3	$ 345.00

Diffusion Area, TOTAL	$ 33,868.00

Wafer Preparation Area		$ 2,347.00
Photoresist Line		12,671.00
Diffusion Area		33,868.00
	TOTAL	$ 48,886.00

CHAPTER 4

METALLIZATION

The vacuum deposition facility at Ames Research Center is capable of doing depositions with resistive films, dielectric films, and other special purpose films. This facility is quite adequate for all deposition work presently used in the fabrication of integrated circuits. However, an additional vacuum deposition system in the integrated circuit laboratory will minimize the additional work load placed on the existing vacuum facility, and it will minimize the possibility of wafer contamination.

The evaporation system consists of a vacuum system, vapor source, substrate holder and heater, and substrate. A typical arrangement of the fixtures used in the deposition of aluminum is shown in Fig. 4-1. The fixtures are mounted on the base plate of the vacuum system. The fixtures may be either fabricated at Ames Research Center or obtained commercially. The evaporation source is a resistance heated boat. The vacuum system is furnished with a 2 KVA high current transformer and a variable transformer for supplying source current. The power is fed through two high current feedthroughs in the base plate. Additional feedthroughs are needed for the substrate heater power and the substrate monitor thermocouple; a rotary feedthrough is used for shutter operation.

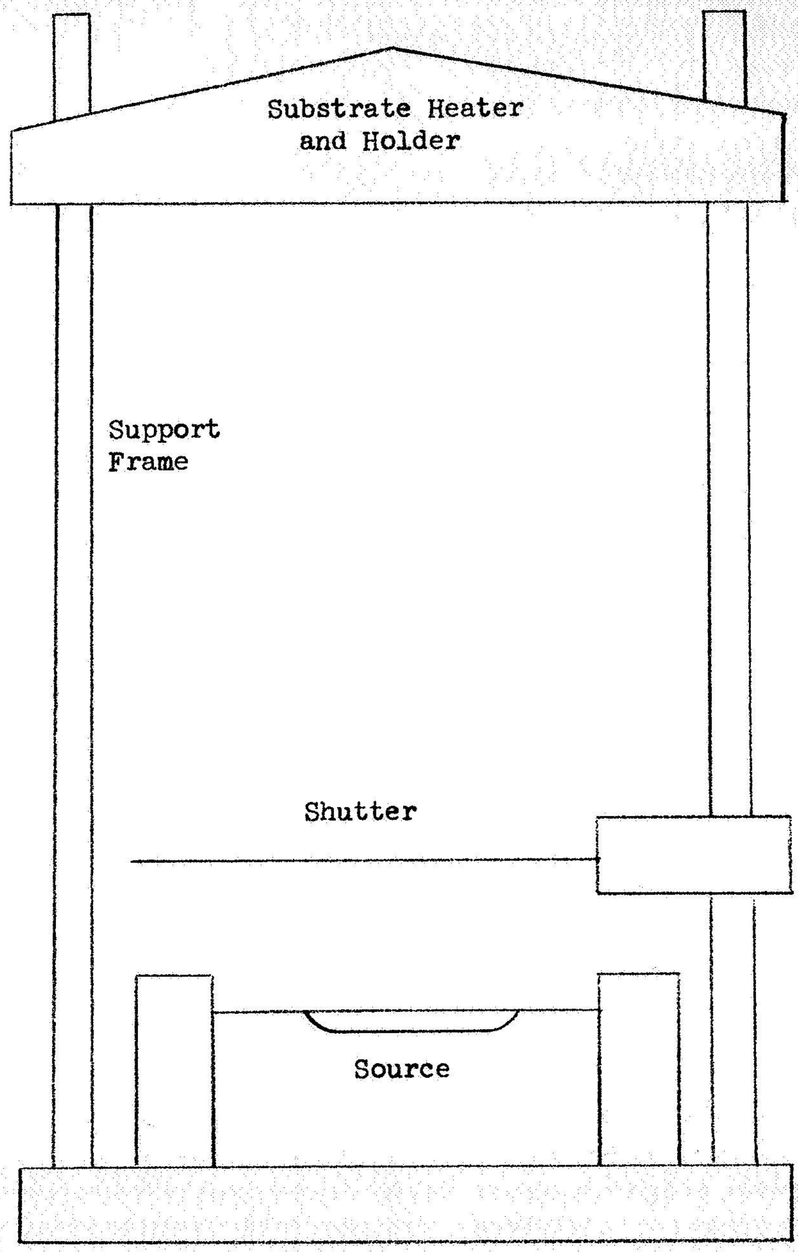

Figure 4-1 Evaporation Fixture

The vacuum system chosen is larger than the minimum useable size. The larger system offers greater pumping speed, lower ultimate pressure, and a more versatile system. This system will be set up initially as a resistive source evaporation unit, but the system may be readily adapted to sputtering and other means of deposition in the future.

A rate and thickness monitor and a controlled power supply are very useful research tools, but for the initial laboratory, they are not required. A certain amount of characterization of the evaporation system will be needed to provide routine deposition rates and thicknesses.

RECOMMENDED EQUIPMENT

Evaporation System, Norton Co.

Description	Number Required	Price
Vacuum Pumping System, Model No. 3117, with VHS-6 diffusion pump and 17.7 cfm roughing pump		$ 5,250.00
Fixturing (est.)		700.00
TOTAL		$ 5,950.00

Alternate Low Priced System

Evaporation System, Edward's High Vacuum Inc., Model No. E12E3 with fixturing		$ 3,633.50
Controller and Heater		385.00
TOTAL		$ 4,018.50

CHAPTER 5

TEST AND ENCAPSULATION

The test and encapsulation area is designed to be utilized by the integrated circuit laboratory and by the hybrid circuit facility. This provides optimum utilization of the equipment necessary to both groups. In the testing and encapsulation of integrated circuits, the circuits are no longer processed as an entire wafer but as individual circuits. In the accept-reject testing, the circuits are attached in wafer form, but each circuit is tested individually. To reduce the cost of labor in working with the individual circuits, additional automation and ease of operation will be considered in equipment selection.

5.1 Testing

The test area is designed to provide the maximum testing versatility.

Figure 5-1 is a flow diagram of the testing area. The test area may be used in testing wafers, hybrid circuits, completed integrated circuits, and a large variety of commercially available devices. The test area provides a means of circuit design evaluation. The configuration of the test equipment is given in Fig. 5-2.

The curve tracer and the integrated circuit tester are used with the probe station to provide wafer testing. The probe station may also be used with special test equipment set up specifically for the

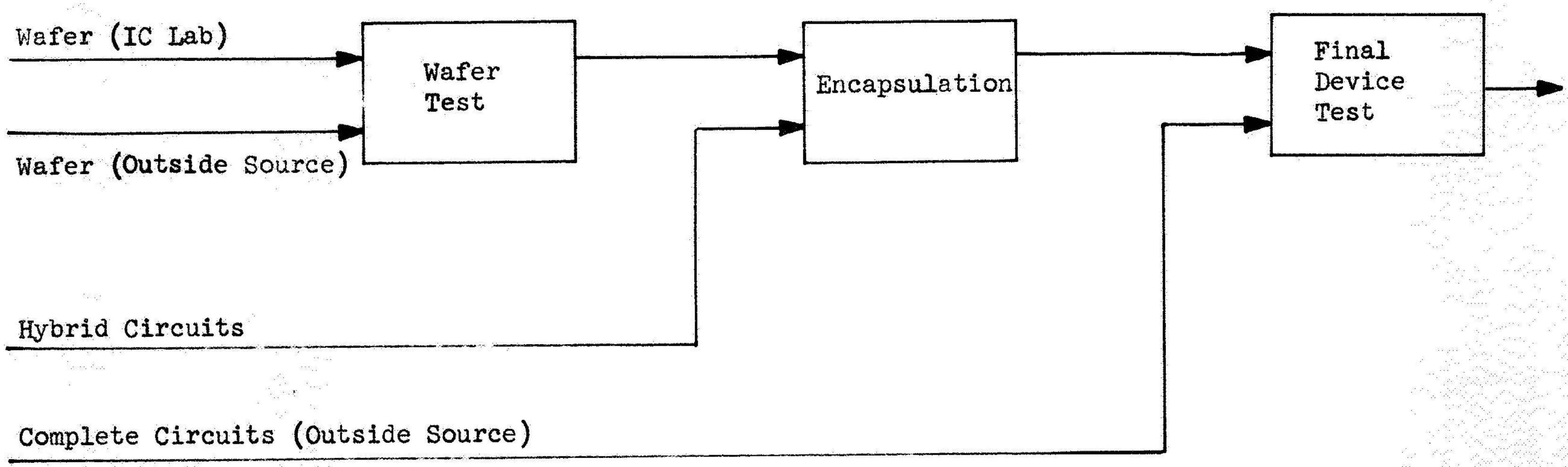

Figure 5-1 Testing Flow Diagram

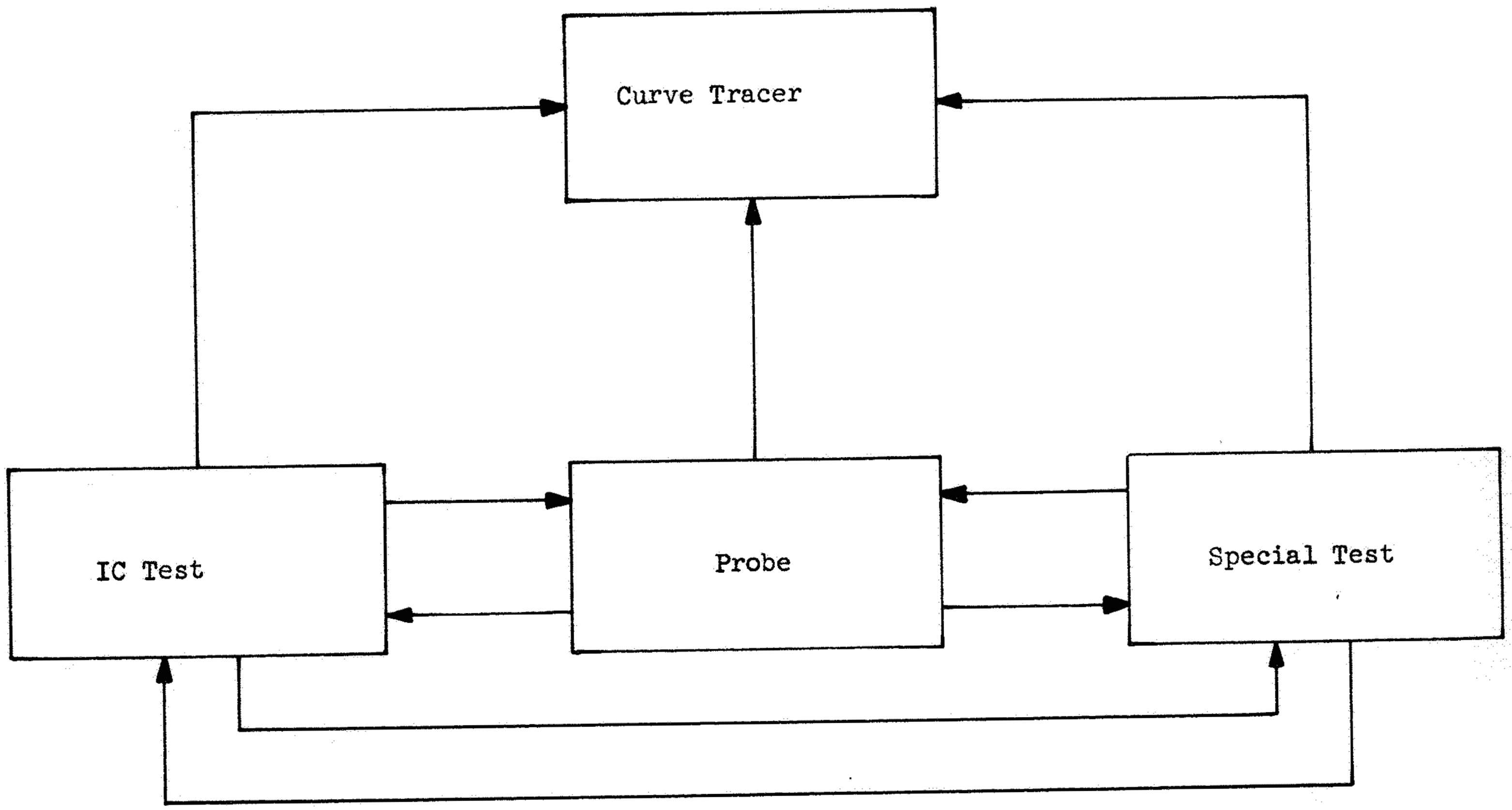

Figure 5-2 Configuration of Test Equipment

device being tested. The curve tracer, integrated circuit tester, and special test equipment are also used in the final test of integrated circuits and hybrid circuits.

Figure 5-3 is a recommended test equipment layout. The regions marked special testing are used for setting up special test equipment which is to be determined by the circuit designer.

The three probe stations considered acceptable are listed below.

Electroglas, Model No. 131B	$3,242.00
Kulicke and Soffa Inc.	3,272.00
TAC, Model No. XY-240	4,330.00

The price of each model includes the basic probe station, ten probes, one inker, and a steromicroscope. The recommended probe system is TAC, Model No. XY-240. The TAC system is preferred because of its ease of operation and wafer positioning controls. The reduction in operation time will more than compensate for the additional cost of the station.

The recommended integrated circuit tester is the Microdyne Model No. 715. The Microdyne tester is capable of testing digital and linear circuits. The testing modes available are crosspoint matrix and prewired patch-plug for semi-automatic testing.

The crosspoint matrix provides device testing and engineering circuit design evaluation. The use of the tester for design evaluation eliminates the need for elaborate arrangements of power supplies and test equipment. All controls are located on the front panel and an analogue meter provides voltage or current readings at any device terminal. Additional test equipment for dynamic or special purpose testing may be directly connected to the matrix.

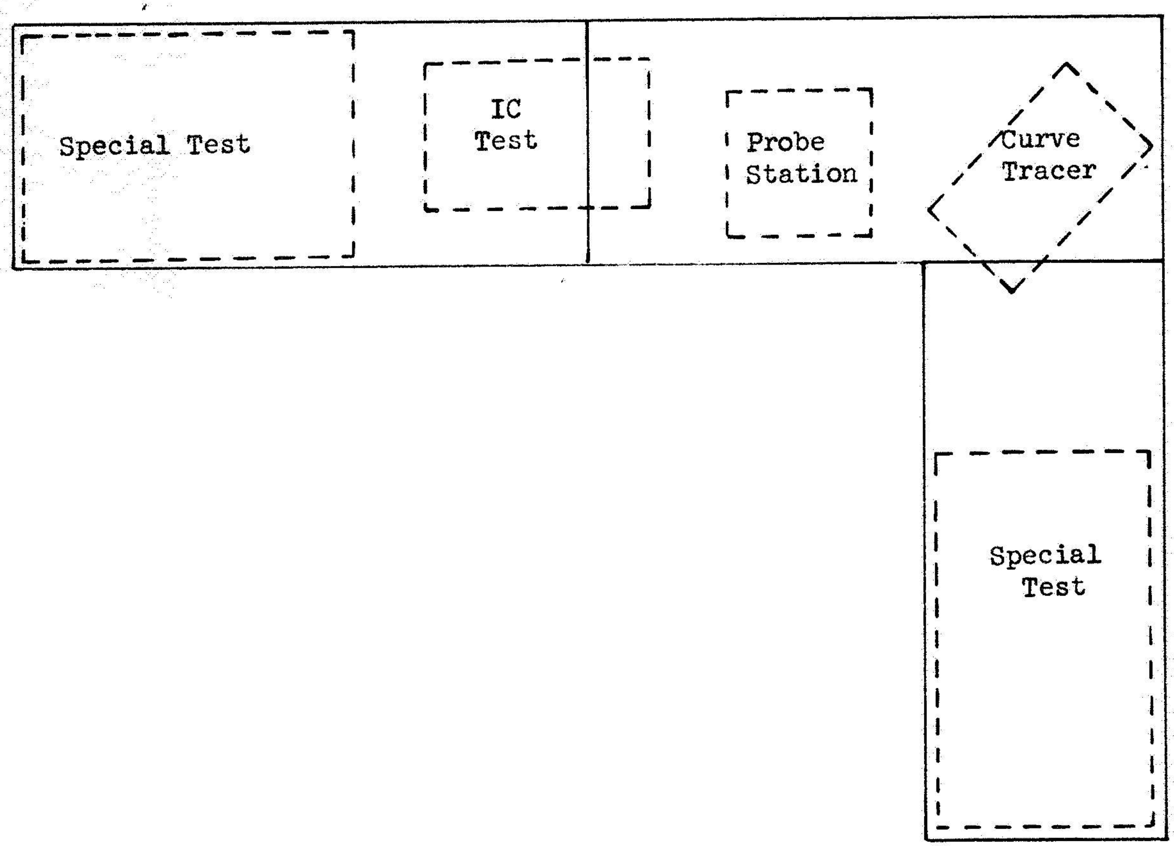

Figure 5-3 Test Equipment Layout

Average testing time with the crosspoint matrix is one minute per device, and the programmed patch-plug reduces this time to approximately 15 seconds.

Programmed patch-plugs are currently available for many commercial integrated circuits. The Microdyne company will supply a programmed plug for any commercial or special purpose circuit for $40.00. The plugs may be purchased separately and programmed by the design engineer.

An additional "Device Holder Connector Card" should be obtained and wired to provide interconnections with the probe station and curve tracer.

The curve tracers considered for the integrated circuit laboratory are:

Fairchild Model No. 6200 B/P	$2,350.00
Tektronix Model No. 575 Mod. 122C	1,475.00
Tektronix Model No. 576	2,125.00

The recommended curve tracer is Tektronix Model No. 576.

This curve tracer can be operated by the design engineer or by a technician. The scale-factor readout will reduce the chance of error in using the curve tracer in accept-reject testing and in the final circuit test.

5.2 Encapsulation

The processes involved in encapsulation is shown in Fig. 5-4. The wafer is scribed and broken into the individual die. The dice are bonded to a header or other suitable package. Following die bonding, the units are then wire bonded and encapsulated. Portions of this

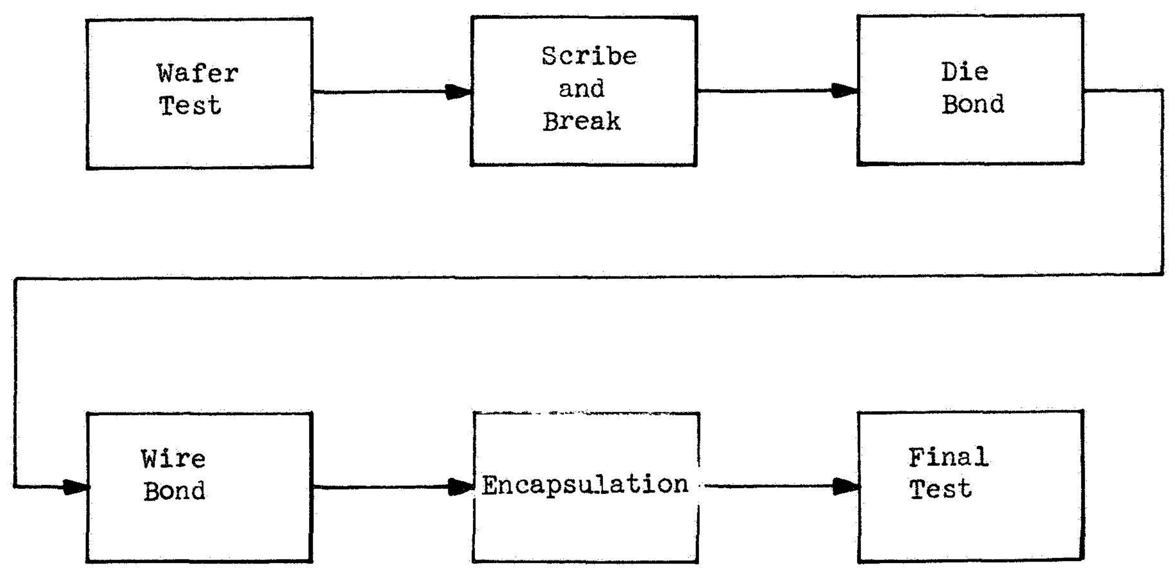

Figure 5-4 Encapsulation Flow Process

process are also common to the hybrid facility. The use of this equipment by both areas will minimize the investment in equipment. The bonding area equipment layout is shown in Fig. 5-5.

The scribing machine recommended is Kulicke and Soffa Model No. 750 MK-II. The scriber is manually operated with a microscope micrometer for tool alignment. The Tempress Model No. 1713-5C is an automatic scribing machine that meets all requirements for the integrated circuit laboratory, but the automation for an additional $2,000.00 cannot be justified. The manual scriber can perform all wafer scribing with no significant increase in labor cost.

Ames Research Center presently owns a Kulicke and Soffa Universal Die Mounter, Model No. 642. The die mounter is adaptable to headers, substrates, and flat packs. The capacity of the mounter is sufficient to handle the work load produced by the hybrid and integrated circuit laboratories. If the output from the hybrid and integrated circuit laboratories became exceptionally high, it may be necessary to purchase an additional die mounter.

A heat die collet with a variac control should be purchased for the die mounter. Top plate assemblies for the various packages may be purchased for $50.00 each.

Wire bonding is a time consuming job; without a sufficient number of wire bonders the production capacities of the hybrid and integrated circuit laboratory would be severely limited. Ames Research Center has an ultrasonic bonder, West Bond Model No. 7175. This bonder should be set up as an ultrasonic wire bonder. A second wire bonder is necessary to provide the required production capacity.

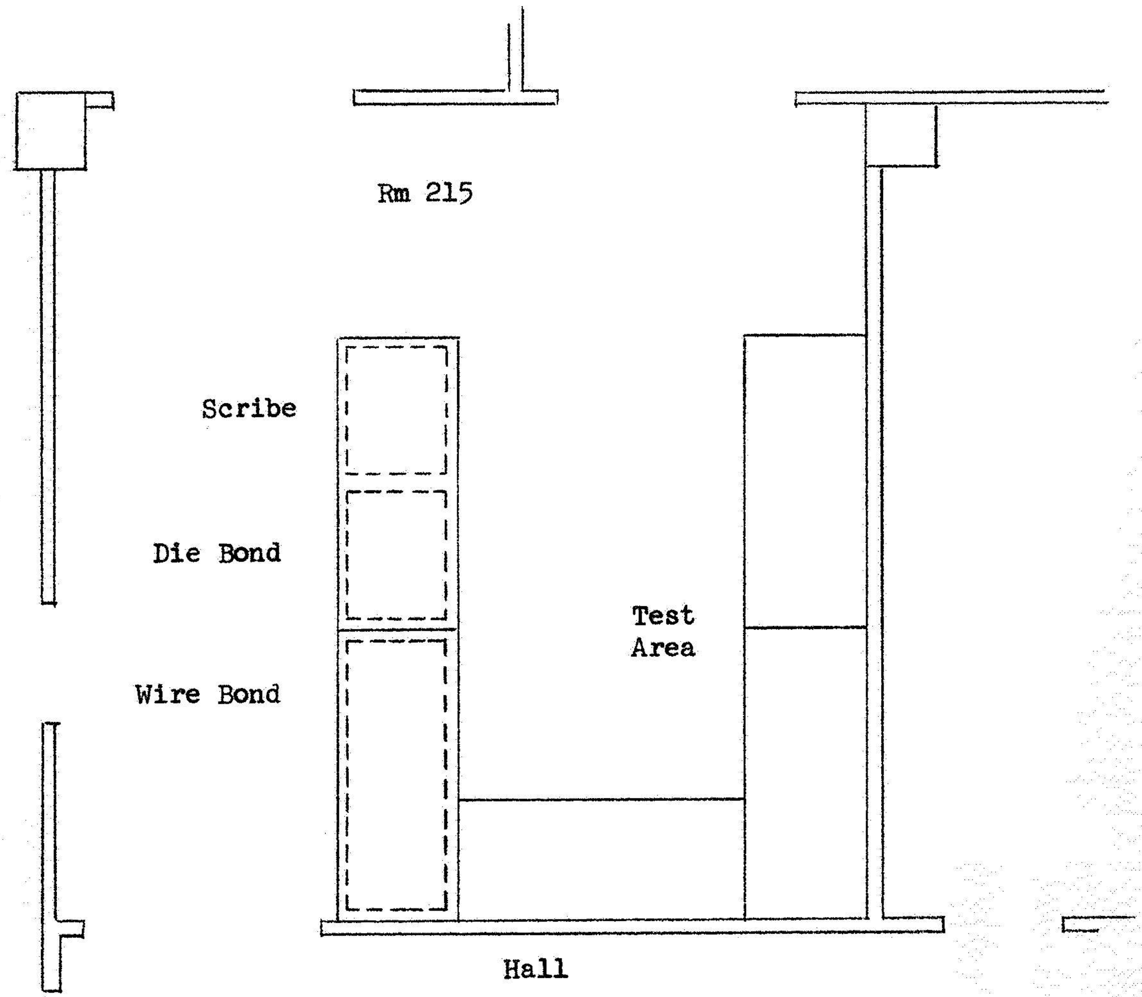

Figure 5-5 Bonding Area Layout

The recommended wire bonder is Kulicke and Soffa, Model No. 484 Ultrasonic Tailless Wire Bonder. This wire bonder is adaptable to all standard packages; it can be used with either gold or aluminum wire; and it can be programmed for semi-automatic operation.

Ames Research Center now owns a welder which can be modified for sealing TO-5 headers. This modification should be made. The circuit design engineers should determine at a later date if other standard packages are necessary.

No cost estimation is given for the welder modification or additional packaging equipment.

RECOMMENDED EQUIPMENT

Description	Number Required	Price
Testing		
Microdyne, Model No. 715	1	$ 2,290.00
Device Holder, Model No. 701-1-2	1	75.00
Adapter Sockets	4	60.00
Programmed Patch Plug	1	40.00
		$ 2,465.00
Probe Station, Tac, Model No. XY-240 (10 probes and inker)	1	$ 4,330.00
Curve Tracer, Tektronix, Model No. 576	1	2,125.00
Test Benches, Bay Co.	3	300.00
Chair, Dependable Manufacturing Co., Model No. 625-M	1	39.00
		$ 9,259.00
Encapsulation		
Scriber, Kulicke and Soffa, Model No. 750 MK-II	1	$ 1,940.00
Die Bonder, Modification	1	100.00
Wire Bonder, Kulicke and Soffa, Model No. 484	1	3,948.00
Test Benches, Bay Co.	2	200.00

Description	Number Required	Price
Chairs, Dependable Manufacturing Co., Model No. 625-M	3	$ 117.00
		$ 6,305.00
TOTAL		$ 15,564.00

CHAPTER 6

SPECIAL AREAS

6.1 Water System

6.1.1 Deionized Water System

A relatively large quantity of ultra pure deionized water is necessary in the processing of integrated circuits. To produce the quality of deionized water required by the integrated circuit laboratory, a water deionizing system must be installed. The system must meet the following requirements:

1. ultra pure water tolerances (Fig. 6-1)
2. flow rate: not less than 2½ gpm
3. low operating cost

The deionized water system is to be placed in Room 216.

The configuration of the deionized water system is shown in Fig. 6-2. The system is recirculating in order to provide a resistivity equal to or greater than 10 megohms in the circulating line. The recirculation of the water will also increase the capacity of the system, minimize water loss, and insure the minimum flow rate.

The analysis necessary for designing the deionized water system is based on the San Francisco Water Department Mineral Analysis Table I, date taken June 3, 1968. The water supplied to Ames Research Center comes from Alameda East Portal (treated water) and Calaveras pipe line (treated water) in a ratio of 4:1 respectively. The water analysis and mixture ratio was provided by Ames Research Center.

	Tolerance, ppm
Fe as Fe	0.005
Cu as Cu	0.005
Organics as O_2 Consumed	1.0
Free Cl as Cl	0
Total Solids	Trace
Specific Resistance	18 megohm-cm
pH	7.0
Size of Particulate Matter	Under 0.5 μ

Figure 6-1 Ultrapure Water Tolerances [Applebaum, 1968, p. 18]

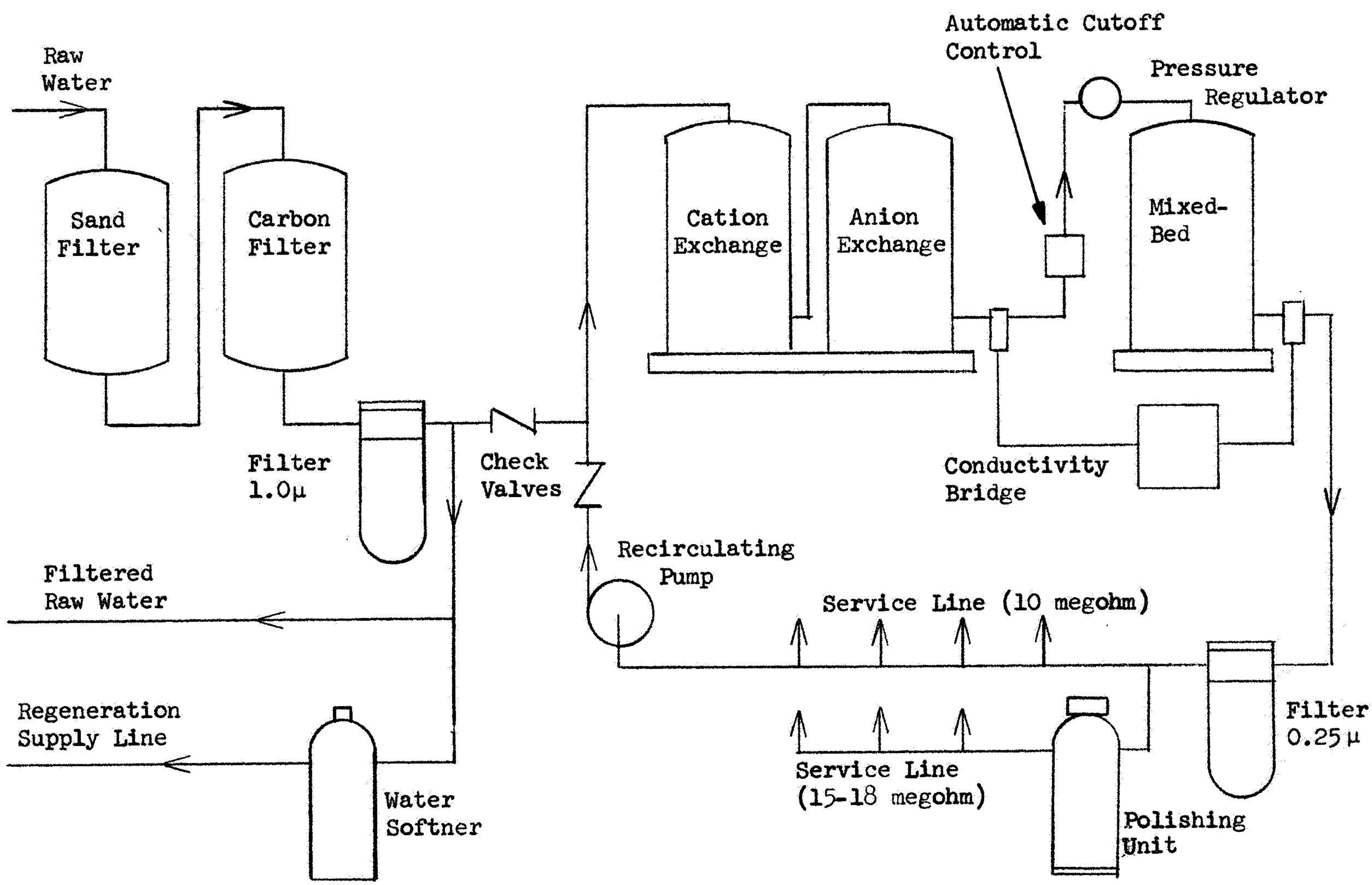

Figure 6-2 Deionized Water System

From the water analysis, the average hardness is 2.1 grains/gallon. The amount of ionizable particles in the water will fluctuate during the day and will also fluctuate with seasonal changes. The system analysis will be calculated using a valve of 5 grain/gallon to allow for changes in the water supply. The capacity of the system will decrease as the hardness increases.

6.1.2 Sand Filter

The sand filter removes suspended matter and turbidity from the effluent which would otherwise clog the micron filters and damage the ion exchange resins.

6.1.3 Carbon Filter

The carbon filter removes odor, color, organic, and free chlorine from the water. The organics and free chlorine will permanently damage the resin if allowed to pass through the deionizing columns.

6.1.4 Filters

The 1.0 micron filter following the carbon filter removes particulate matter before the water enters the cation bed. The final filter insures that the circulating line will be free of particulate matter larger than 0.25 microns.

6.1.5 Two-Bed Deionizer

The cation and anion exchange columns are furnished as a single unit. The input line to this unit has an integrating water meter and rate meter. An indicating conductivity meter is located on the front panel for monitoring the purity of the effluent. An additional probe is to be placed in the service line following the mixed-bed deionizer.

The conductivity meter is to be provided with a switch that will allow the resistivity to be read from either probe.

The input pressure shall be regulated at 75 psig, and the input water line should not be less than one inch in diameter. The maximum flow rate is 350 gph.

The two-bed deionizer will provide 8,000 gallons of water per regeneration cycle. Assuming a hardness of 5 grains/gallon and a consumption rate of 200 gallons per day, this unit will need to be regenerated every 40 working days.

The effluent quality will normally be less than 5-10 ppm.

6.1.6 Automatic Shut-Off System

The automatic shut-off system measures the resistivity of the water, and when the resistivity drops below a set value, the water flow is terminated. The system is provided with an alarm to indicate that regeneration is necessary.

6.1.7 Mixed-Bed Deionizer

The mixed-bed deionizer acts as a polishing unit to increase the resistivity of the water to not less than 10 megohms. The flow rate is 150 gph. Two pressure regulators are needed to insure that the column pressure does not exceed 50 psig. One regulator is located in the soft water line feeding this unit, and the other regulator is located in the input water line.

The mixed-bed deionizer will provide 10,000 gallons of water per regeneration. At 200 gallons per day, this unit will need to be regenerated every 50 days.

6.1.8 Service Line

The location of the recirculating service line is shown in Fig. 6-3. The service line is to be rigid 3/4 inch PVC. This line must be well supported and thermal expansion must be considered in the line installation.

The service line is returned to the deionizing system through a stainless steel pump. Two check valves are required to provide proper water flow. The location of the check valves are shown in Fig. 6-2.

6.1.9 Photoresist and Diffusion Service Line

The highest quality of water is required in the photoresist and the diffusion area. A non-regenerable mixed-bed deionizer is placed in the photoresist service line. The water at the service outlets will have a resistivity of 15 to 18 megohms.

The non-regenerable deionizer has a capacity of 8,000 grains. If 10 megohm water is supplied to this unit, the life capacity is 45 million gallons. This valve is not realistic, but a lifetime of one year or more can be expected. The price of a new charge of resin is \$85.00. The new resin would be placed in the deionizer, and the depleted resin removed and used in the mixed-bed deionized Model No. MB-535. A purity meter is included as part of the Model No. RC-700.

6.1.10 Water Softener

Soft water is required in the regeneration of the two-bed and mixed-bed deionizers. The recommended model will provide the correct flow rate and the quantity of soft water necessary for regeneration.

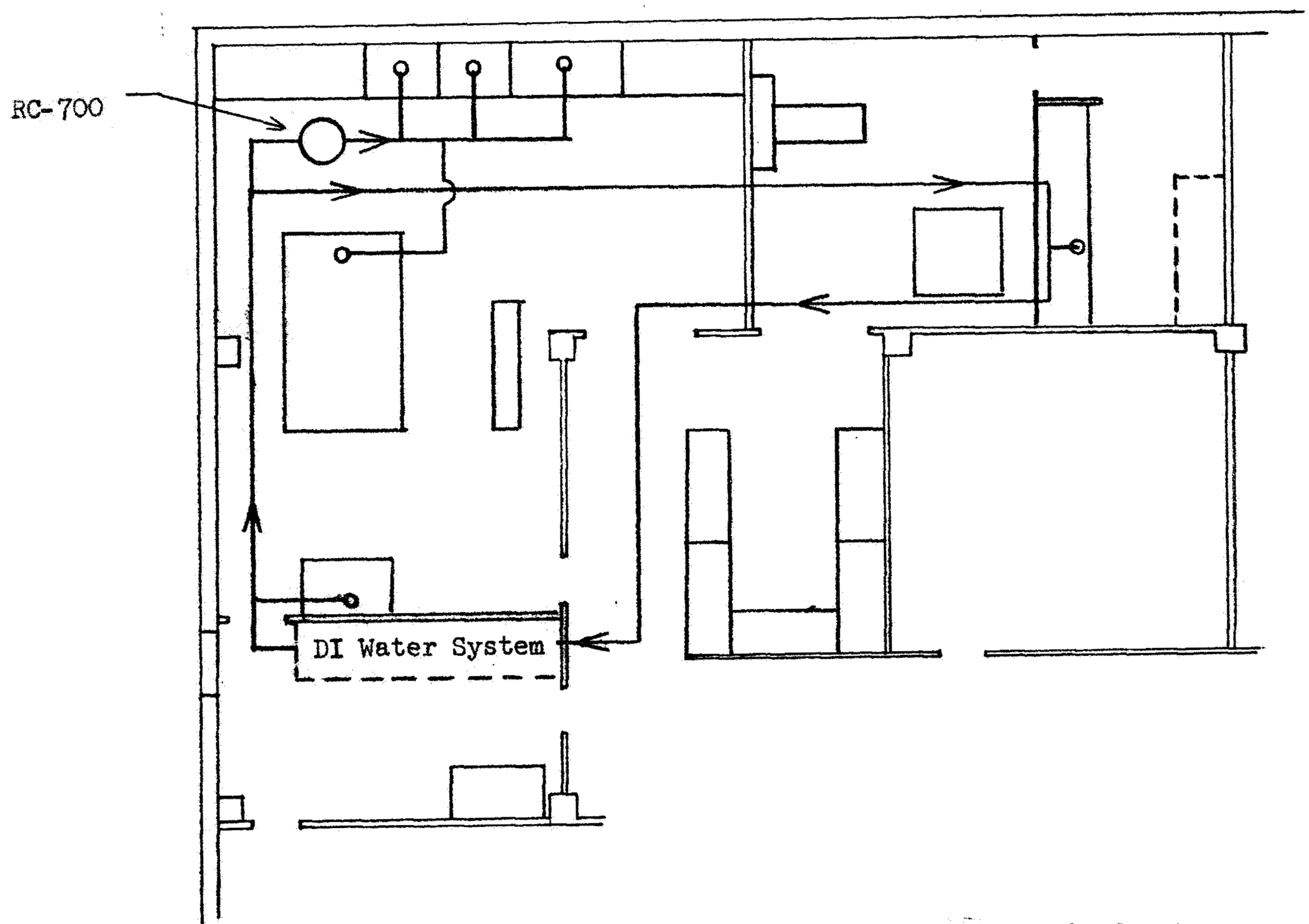

Figure 6-3 Service Line Location for Deionized Water

6.1.11 Plumbing System

The water supply line to the system must have a flow rate of not less than 20 gpm and a static pressure of not less than 75 psig. The supply line should be rigid copper tubing with soldered joints. An open drain system capable of draining 20 gpm must be installed for recycling the various units. Nitrogen gas is also required at 20 psig.

All pipe interconnecting the various units is to be made of PVC. The service line and all service outlets are to be made of PVC. It is of great importance that only teflon tape be used in joining the PVC pipe. Any other joint compound will contaminate the system and cause severe damage. The drain may be made of copper.

6.1.12 Resin

The mixed-bed and two-bed deionizers are furnished with resins. The non-regenerable polishing deionizer is shipped with resin TM-12; the resin should be changed to TMD-12. The two resins are the same except that resin TMD-12 has an indicating dye which is needed at the time the resin is exhausted and transferred for use in the mixed-bed deionizer Model No. MB-535.

6.1.13 Estimated Cost

All equipment is made or supplied by Illinois Water Treatment Company. The cost estimation does not include installation, installation materials, pipe lines, service outlets, drain line or other building modifications.

6.2 Time Required for Standard Processing of an Integrated Circuit

6.2.1 Artwork

Assuming that the artwork is cut over the circuit layout, the artwork cutting time is approximately two hours per mask for normal circuit complexity. The total cutting time for a set of five masks is ten hours.

6.2.2 Mask Generation

The time required for mask generation depends on the system used. Outside mask sources can provide finished masks in less than one week. The David Mann camera system required 48 hours. The 48 hours is the total processing and drying time. Eight man hours are required to produce a set of five masks. The fly's eye camera system requires two-and-one-half man hours and a total of 24 processing and drying hours.

6.2.3 Photoresist and Diffusion

Normal wafer processing time is approximately one week. One laboratory technician can process an average of 30 wafers per week if all processes are standard.

6.2.4 Metallization

Two hours is sufficient time to allow for evaporator set-up and evaporation.

6.2.5 Die Processing

The assumptions made in deriving operation times are:

1. Die size: 100 mils x 100 mils
2. 12 bonding pads per die
3. TO-5 header, 12 leads

4. One inch wafer, 60 die per wafer

5. 100 per cent yield

Operation times:

Function	Per Die	Per Wafer
1. Wafer testing (simple test)	30 sec.	30 min.
2. Scribe	---	15 min.
3. Clean	---	30 min.
4. Die bond	15 sec.	15 min.
5. Wire bond	60 sec.	60 min.
6. Encapsulation	30 sec.	30 min.
7. Test: Programmed	15 sec.	15 min.
Manual	60 sec.	60 min.
Special	---	---

6.2.6 Manhours Per Wafer

The following assumptions are made in calculating the manhours per wafer.

1. Ten wafers processed together

2. Standard processing times given in previous section

3. David Mann camera system

	Total Time (hours)	Time Per Wafer (hours)
Artwork	10.0	1.0
Mask Generation	8.0	.8
Photoresist and Diffusion	40.0	4.0
Metallization	4.0	.4
(5 wafers per evaporation)		
Dice Processing	32.5	3.25
Total Process Time	94.5	9.45

6.3 Manpower Requirements for Integrated Circuit Laboratory

The integrated circuit laboratory requires one laboratory engineer and two technicians for developing and operating the laboratory.

The laboratory engineer is responsible for the operation and supervision of the integrated circuit laboratory. His prime functions are: process development, work scheduling, engineer training, design consulting and supervising. Administrative duties of the laboratory engineer should be minimized to allow engineering time for the laboratory and process development. The engineer is not to act as an integrated circuit designer, but as a consultant to other design engineers to insure that their designs are compatible with the fabrication processes.

The layout and cutting of the artwork will be the responsibility of a draftsman. An experienced draftsman will require a minimum amount of training on the coordinatograph.

The deionized water system is to be maintained by the building engineering department. One man should be given the responsibility of regenerating and maintaining the water system. A weekly preventive maintenance check is necessary; the integrated circuit laboratory personnel should keep a log of the water used and notify the building engineer when the system requires regeneration.

6.4 Schedule for Laboratory Development

The schedule for laboratory development itemizes the development work and the approximate development times. The laboratory is developed by two simultaneous routes. The two routes are shown in Fig. 6-4. The itemized scheduled is given in Tables 6-1 through 6-4.

6.5 Gas Supply System

The furnace system requires extremely high purity gases for wafer processing. The gases presently available in the building are not adequate. A separate gas storage area is necessary to supply high purity nitrogen and oxygen. The doping gas supplies are in the gas control cabinets at the rear of each furnace stack.

The gas supply system is shown in Fig. 6-5. Separate systems are needed for oxygen and nitrogen. The automatic switching system allows switching between manifolds without interrupting the gas flow. The nitrogen supply system has eight stations, and the oxygen supply system has four stations.

The supply lines from the gas storage area to the gas control cabinets should be installed by a contractor. High purity line standards should be followed during the installation of the lines.

The oxygen and nitrogen supply lines branch out to provide gas to each gas control panel. The branching configuration is shown in Fig. 6-6. The supply lines have a line regulator in each gas control cabinet. All supply lines from gas storage area to the furnaces are ½ inch copper pipe, type K. If the nitrogen from the gas storage area is to be used in other areas, the supply line from the switching manifold to the branching point should be 3/4 inch copper pipe, type K. The supply lines after the line regulators are constructed of ½ inch

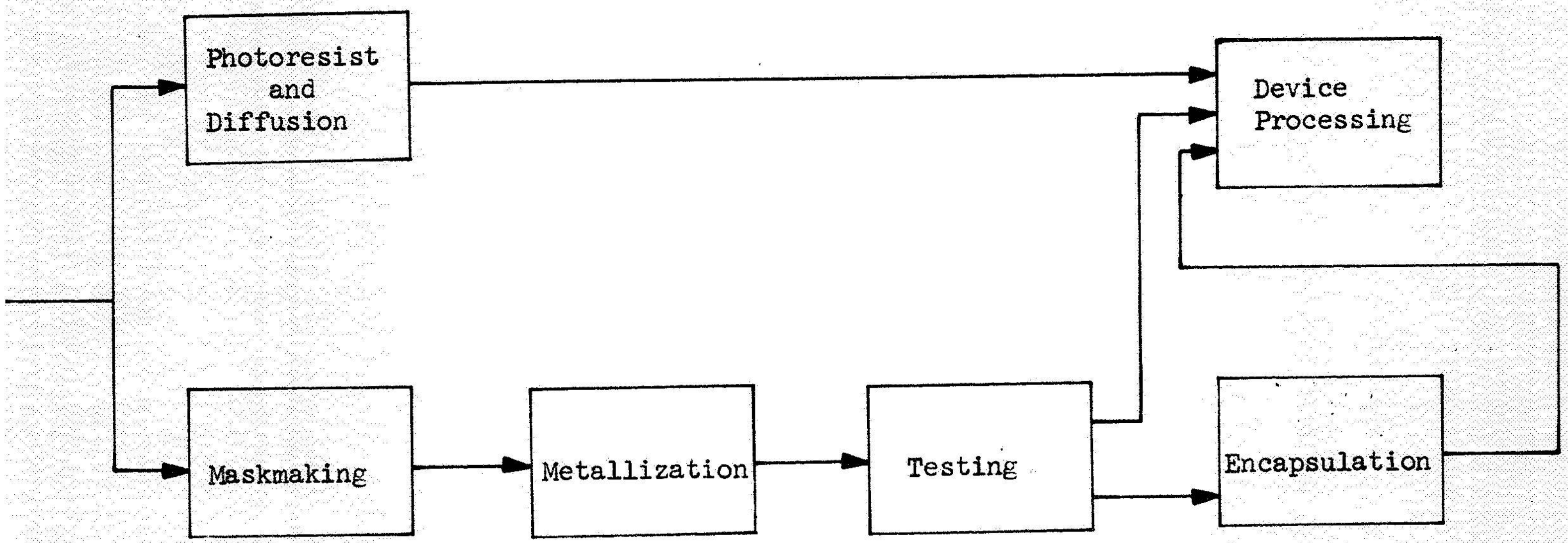

Figure 6-4 Development Work

TABLE 6-1

PHOTORESIST AND DIFFUSION DEVELOPMENT

Work Description	Persons Responsible for Work	Time (Weeks)
Laboratory Supply Ordering, Laboratory cleaning and supply location	Lab Engineer Technician No. 1	4
Gas Control Panel Plumbing	Technician No. 1 or Additional Technician	4
Development of Wafer Cleaning process	Technician No. 1	1
Development of Photoresist Process	Technician No. 1	2
Glassware Cleaning and Furnace Turn-on	Technician No. 1 Lab Engineer	1
Furnace Profile, (Oxidation and Drive-in Barrels)	Technician No. 1	1
Development of Oxidation Process (Steam and Dry O_2)	Technician No. 1 Lab Engineer	2
Diffusion Barrels, Profile and Doping Gas On. (Boron and Phosphorus)	Technician No. 1	1
Furnace System Characterization and initial process Development (Boron and Phosphorus)	Lab Technician No. 1 Lab Engineer	12

TABLE 6-1 (Continued)

Transistor Processing	Lab Technician No. 1	2
Engineering Evaluation	Lab Engineer	
Total Time		30

TABLE 6-2

MASKMAKING

Work Description	Persons Responsible for Work	Time (Weeks)
Coordinatograph Set-up and Operation	Draftsman Technician No. 2	1
Photographic Processing	Technician No. 2 Photo Lab Technician	1
Camera Set-up and Operation	Technician No. 2 Photo Lab Technician	6

TABLE 6-3

ENCAPSULATION AND TESTING

Work Description	Persons Responsible for Work	Time (Weeks)
Scribing, Die Bonding, Wire Bonding, and Packaging	Technician No. 2	2
Curve Tracer Operation	Technician No. 2 Lab Engineer	1
I.C. Tester Operation	Technician No. 2	1
Probe Station Operation	Technician No. 2	1
Test System Interconnection	Technician No. 2 Lab Engineer Electronic Technician	2

TABLE 6-4

METALIZATION

Work Description	Persons Responsible for Work	Time (Weeks)
Vacuum System Set-up and Operation	Technician No. 2 Vacuum Facility Technician	1
Metalization Process Development	Technician No. 2 Vacuum Facility Technician	4
Total Schedule Time for Technician No. 2		20

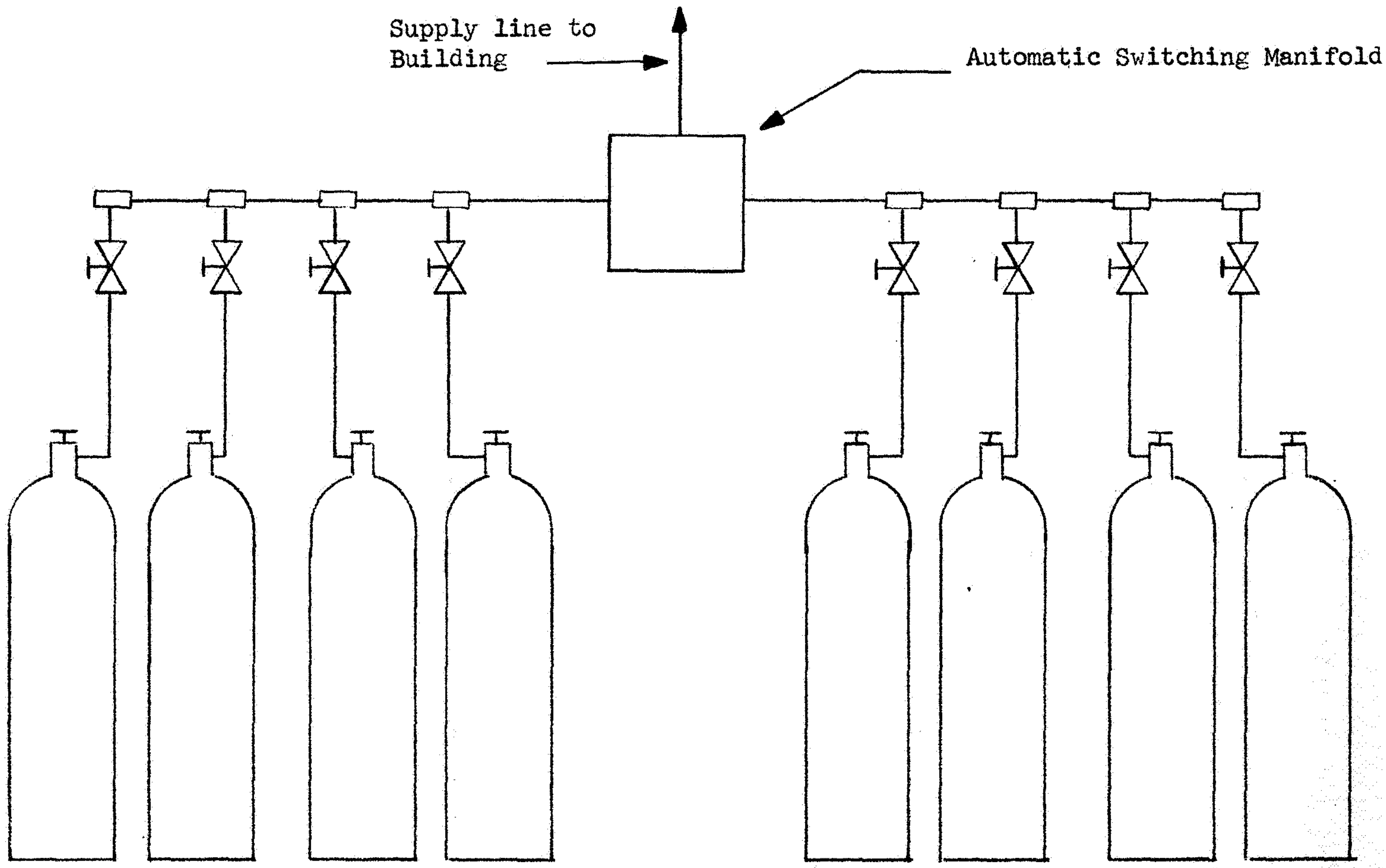

Figure 6-5 Gas Supply and Automatic Switching Manifold

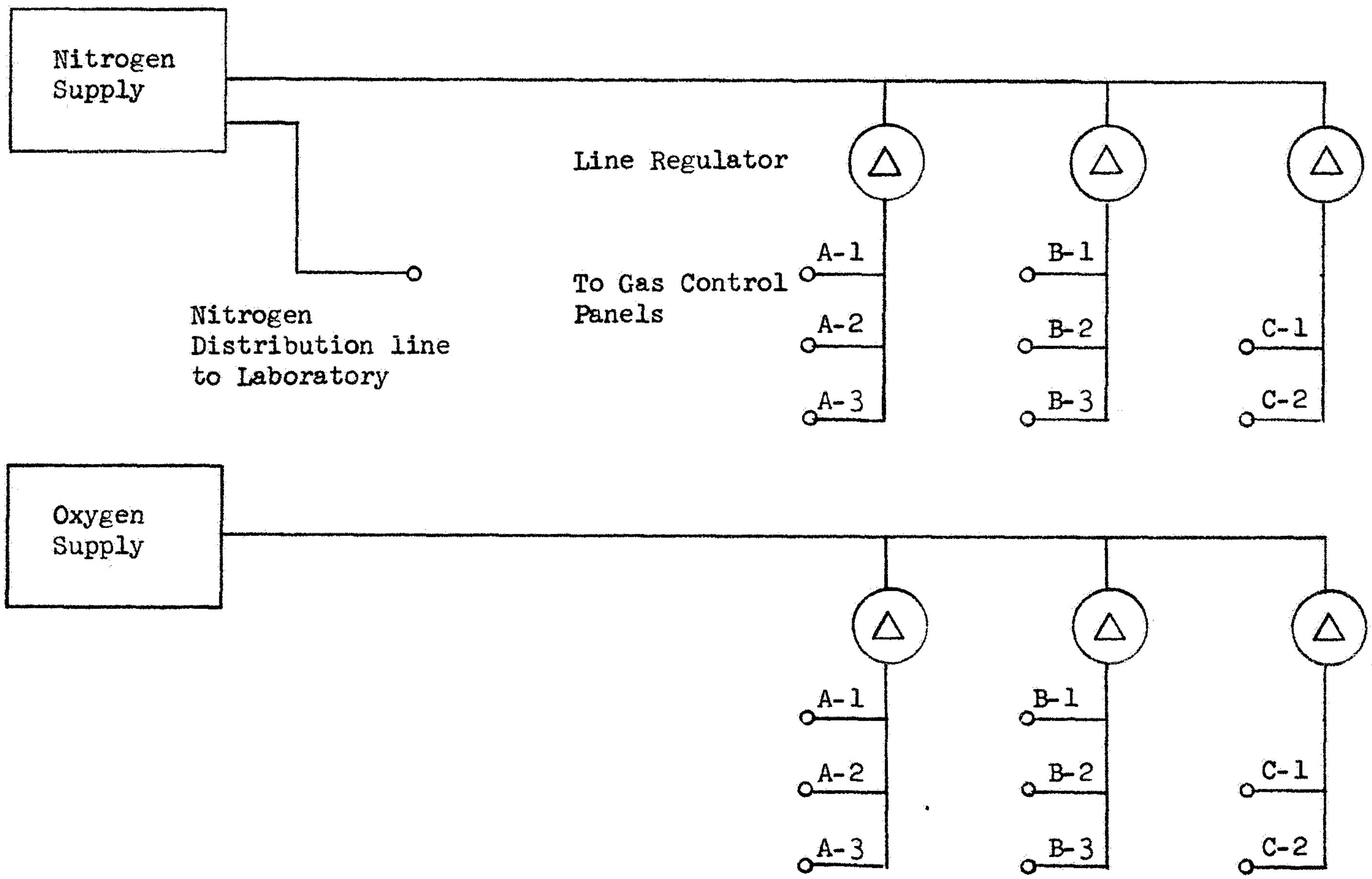

Figure 6-6 Nitrogen and Oxygen Distribution System

copper pipe, type K. The branch to each control panel is to have a 1/4 inch NPT - to - 1/4 inch tubing adapter. Figure 6-7 illustrates the end of the branch line.

6.6 Building Modifications

6.6.1 Walls and Ceiling

The ceiling should be lowered a sufficient distance to cover elevated pipes and fixtures. The windows should be sealed and covered with a permanent wall; the walls should be painted a light color that is easily washed.

The interior wall changes are shown in Fig. 6-8. The door between Rm. 215 and 215a and the door between Rm. 215 and 211 should be sealed and covered in the same manner as the windows. The door into the photographic darkroom must be light tight; all other doors in the laboratory should be fitted with small windows for safety.

6.6.2 Lighting

The fixtures for the fluorescent lights should be recessed into the ceiling to prevent dust collection. All areas should have white lighting; and in addition to white lighting, the diffusion - photoresist area should have a separate line of gold fluorescent tubes that may be turned on independently of the white lighting. A red safety light is located over the counter in the photographic processing area.

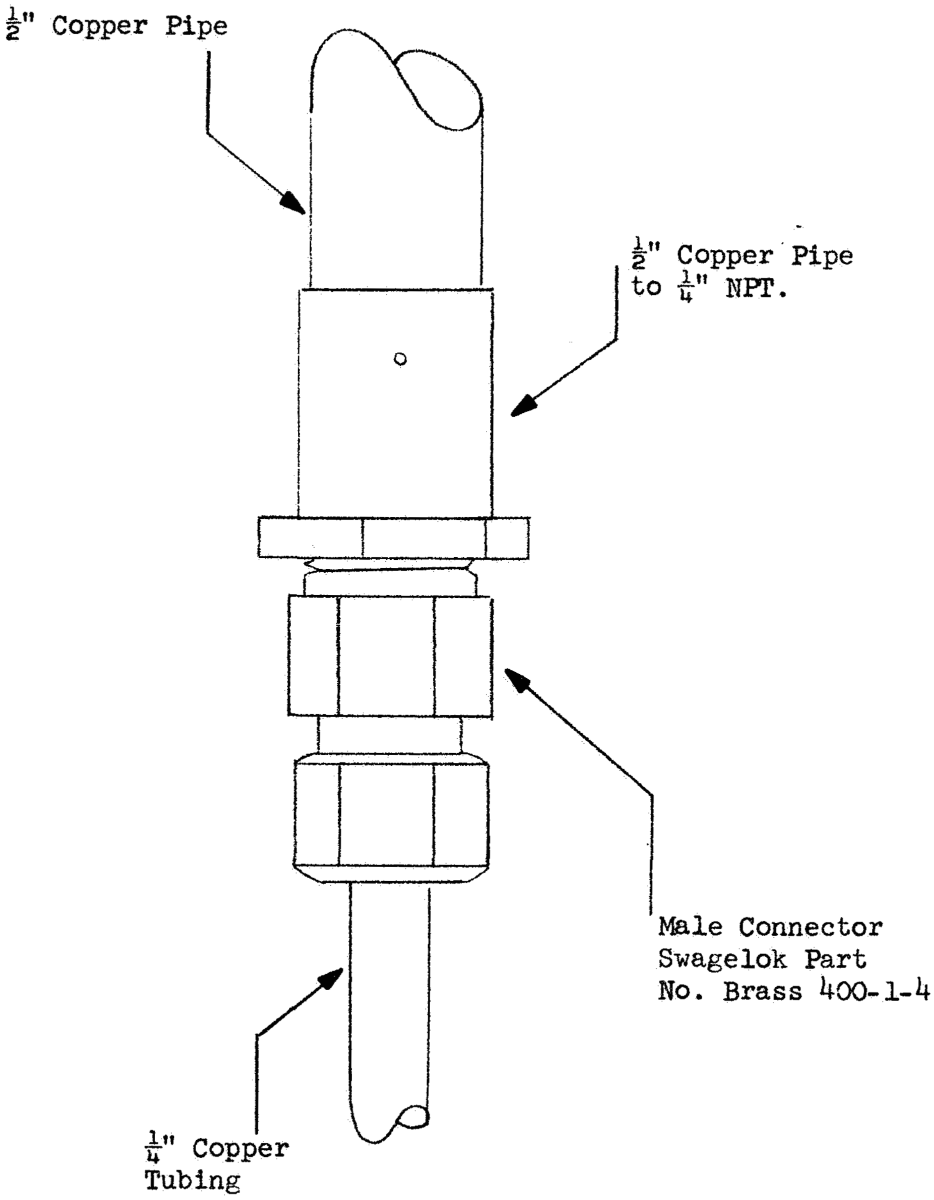

Figure 6-7 End of Branch Line in Gas Control Cabinet

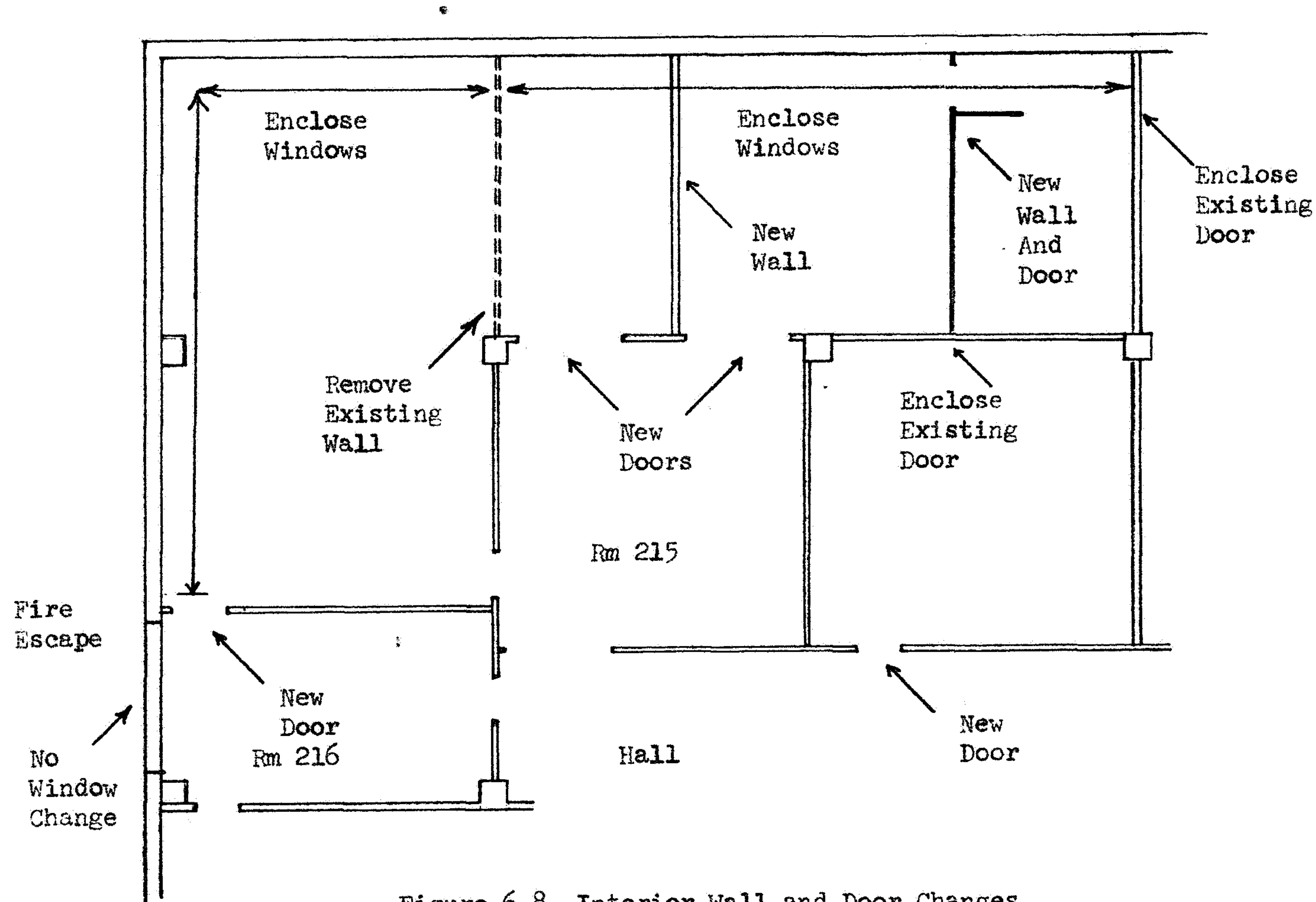

Figure 6-8 Interior Wall and Door Changes

6.6.3 Electrical Power

The furnace chambers require 64 kilowatts of power; however, the power lines should be run at 50 percent capacity. The power requirements of the laboratory are listed below.

Furnace chambers	128.0 KW
Furnace controls	1.5 KW
Gas control cabinets	3.0 KW
Photoresist line	10.0 KW
Wafer preparation	10.0 KW
Maskmaking	10.0 KW
Encapsulation and testing	15.0 KW
Maximum required power	177.5 KW

An emergency power source must be provided for the diffusion furnaces; the required power is 64 kilowatts.

6.6.4 Drains

The location of the required drains is shown in Fig. 6-9. All drains should be chemical resistant; the drain line for the deionized water system in Rm. 216 may be copper. Waste treatment should be provided to comply with building and city codes.

6.6.5 Floors

The laboratory floor should be covered with a non-porous chemical resistant floor covering.

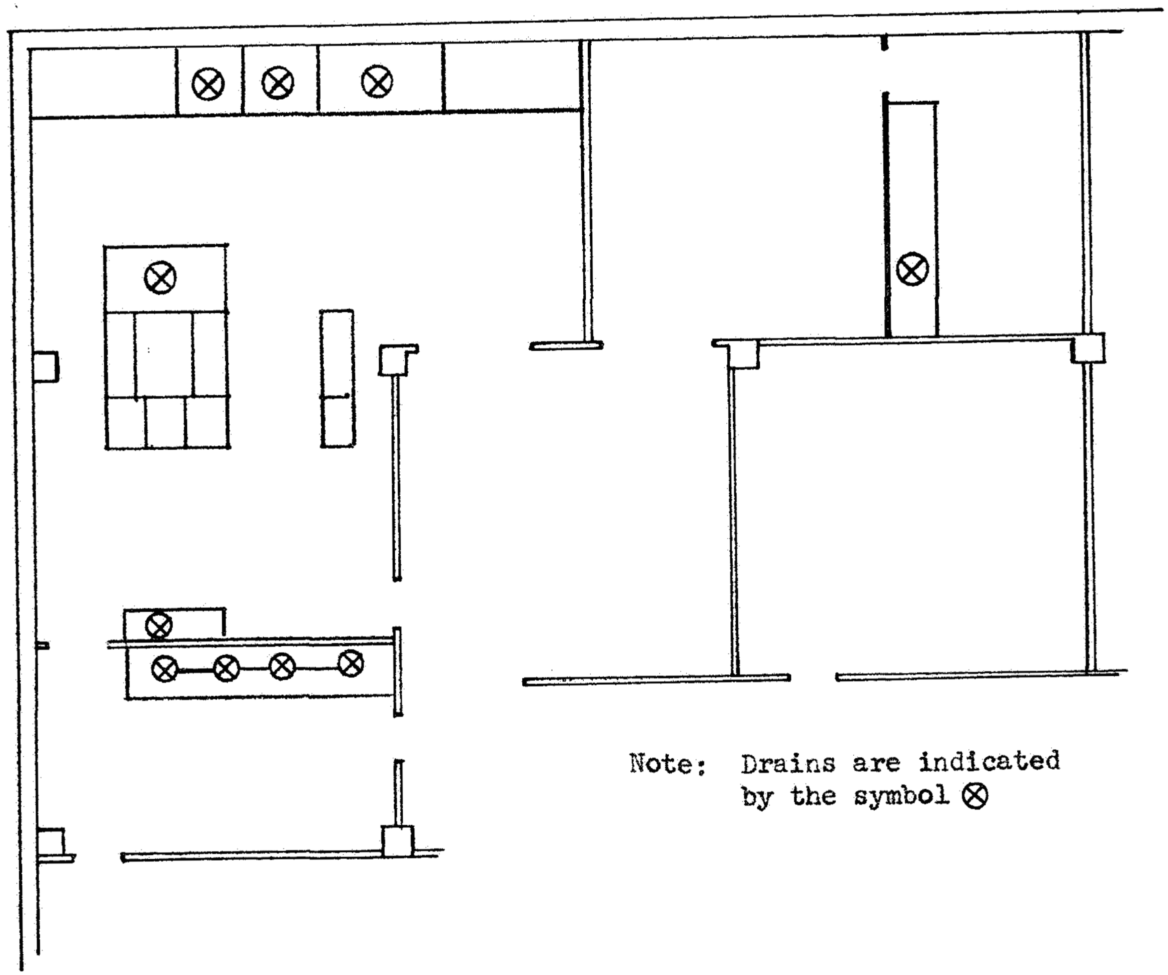

Figure 6-9 Location of Drains

6.6.6 Rear Sink

A general purpose sink is located along the rear wall of the diffusion - photoresist area.

6.6.7 Safety Equipment

An eyewash and shower should be located within the diffusion - photoresist room. Additional equipment such as medical oxygen, first aid box, gas mask, chemical protective clothing, and a fire extinguisher should also be provided in the laboratory area.

6.6.8 Chilled Water System

The vacuum system and furnaces require chilled water for cooling; the furnaces require 6.75 gpm, and the vacuum system requires 0.35 gpm. The chilled water system should be rated at 12.0 gpm or greater to provide for future expansion.

6.6.9 Vacuum Line

The location of the vacuum line and service outlets is shown in Fig. 6-10. The vacuum line is to be constructed from 2" copper tubing and each service outlet is to have a value and snap-on line connector. The vacuum pump must have a vacuum of 27 inches of mercury at a rate of 12 cfm. The vacuum pump may be located outside of the integrated circuit laboratory.

6.6.10 Filtered Water Service Line

A service line for filtered water should be installed parallel to the deionized water line.

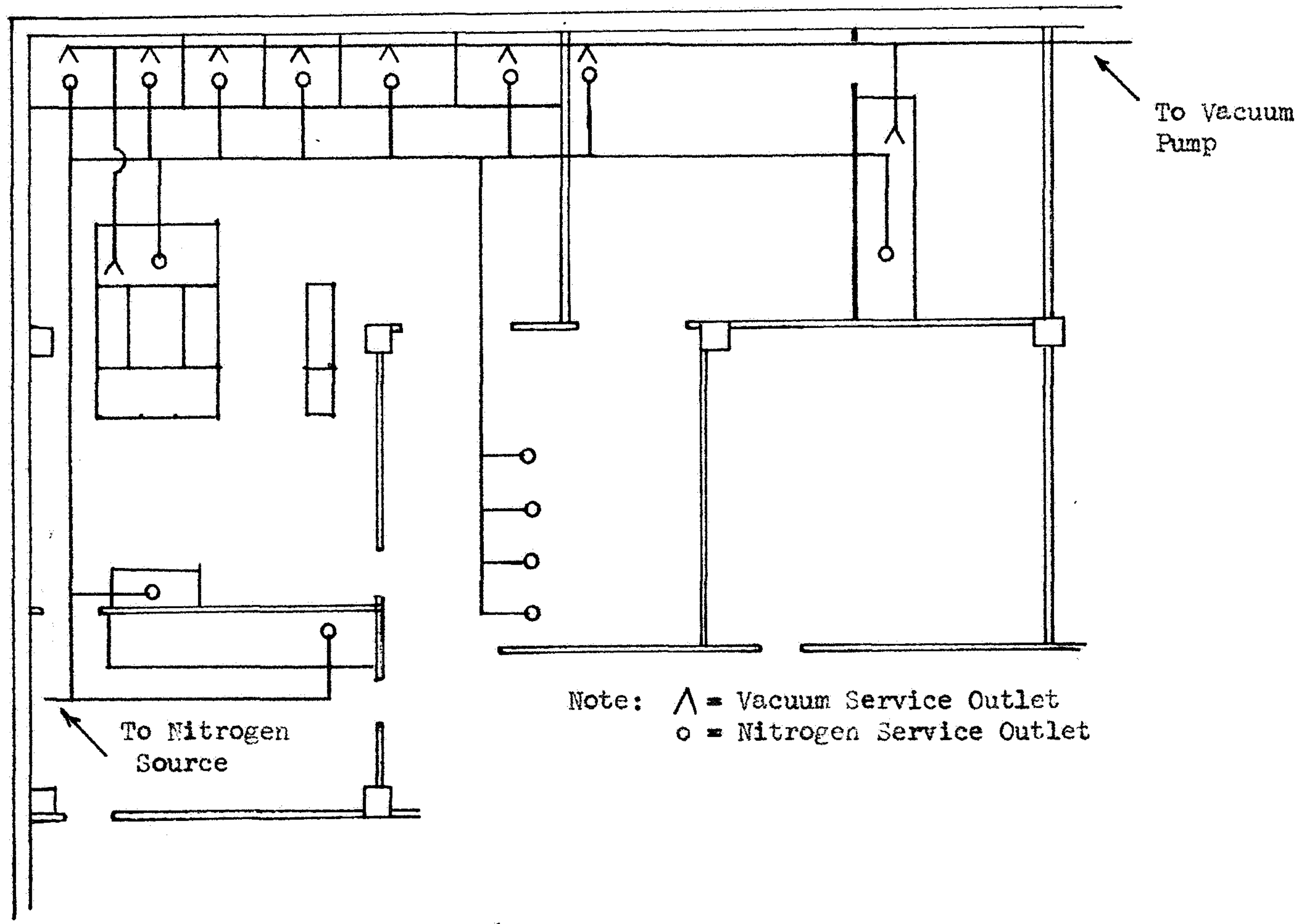

Figure 6-10 Location of Vacuum and
Nitrogen Service Lines

6.6.11 Nitrogen Service Line

The location of the service outputs for the nitrogen service line are shown in Fig. 6-10. The source of nitrogen may be the nitrogen service line presently in the building or a nitrogen service line from the new gas storage area.

6.6.12 Exhaust System

An exhaust system is needed for the diffusion furnaces, gas control cabinets, laminar air exhaust hoods, and the chemical exhaust hood.

6.7 Additional Equipment

In the operation of the integrated circuit laboratory a system for lap and stain and a system for sintering will be needed. It is recommended that both systems be built by Ames Research Center.

An inspection microscope and a four point probe are needed for laboratory operation.

RECOMMENDED EQUIPMENT

Description	Number Required	Price
Gas Supply and Automatic Switching Manifold System, Matheson Co.		
Nitrogen		
Central Control Section	1	$ 185.00
Stations and Valve	8	256.00
		$ 441.00
Oxygen		
Central Section	1	$ 185.00
Station and Valve	4	128.00
		$ 313.00
Cylinder Holder, Wall mounted Model No. 510	12	$ 91.20
Line Regulator, Model No. 40	6	156.00
Male Connector, Swagelok Part No. Brass 400-1-4	16	13.80
		$ 261.00
Gas Supply System TOTAL		$ 1,015.00
Deionized Water System, Illinois Water Treatment Co,		
Sand Filter, Model No. SC 212	1	200.00
Carbon Filter, Model No. CC 212	1	274.00
Water Softner, Manual, Model No. R-2104	1	209.00
Mixed Bed, Non-regenerable, Model No. RC-700	1	395.00
Automatic Shut-off for HB-455	1	245.00
Purity Meter, Model RE-146Y1	1	225.00
Additional Cell for Purity Meter Model No. VYOO 1T-z6	1	110.00
Two-bed Deionizer, Model No. HB-455	1	1,950.00

Description	Number Required		Price
Mixed-bed Deionizer, Model No. MB-535	1	$	995.00
Pump, re-circulating	1		362.00
Micron Filters	2		106.00
Pressure Regulators	2		60.00
Check Valves	2		30.00
Modification to Purity meter, switch	1		20.00
		$	5,181.00
Lap and Stain		$	500.00
Sintering System			500.00
Four Point Probe			500.00
Inspection Microscople, Unitron Model No. BMKK-A4			380.00
TOTAL		$	8,076.00

CHAPTER 7

DESIGN CONCLUSIONS

The integrated circuit laboratory has been designed to provide a functional facility for integrated circuit research and fabrication. The laboratory configuration is planned to allow for additional expansion and modifications as equipment and processes change.

Facility Cost:

Photoresist - Diffusion Area	$48,886.00
Maskmaking	
1. David Mann System	52,660.00
2. Fly's Eye System	18,810.00
3. Outside Source	5,739.00
Metallization	5,950.00
Testing and Encapsulation	15,564.00
Special Areas	8,075.00

The variation in total cost is dependent on the maskmaking system used; the following totals are listed with respect to the maskmaking system.

Total Cost Using:

1. David Mann System	$131,136.00
2. Fly's Eye System	97,286.00
3. Commercial mask source	84,215.00

APPENDIX A

ERROR ASSOCIATED WITH MASKMAKING

The analysis of the error associated with each step in generation of a set of masks is necessary to insure that the desired geometrical dimensions are compatible with the maskmaking system.

A.1 Reduction Camera

The reduction camera must use an extremely high quality lens to prevent image distortion and to provide sufficient resolution over the image plane. Focusing and camera positioning are the two major sources of error associated with a reduction camera.

The depth of focus, ΔF, is the interval over which the image plane is considered in focus.

$$\Delta F = 2.44\, \lambda \left[\frac{F}{D}\right]^2$$

F: focal length of lens

D: diameter of lens

λ: wavelength of light

The depth of focus for lenses used in reduction cameras is typically less than 1 mil at a wavelength of 5,500 A. A microscope mounted behind the image plane is necessary to focus the camera and insure the correct reduction ratio.

The lens to copyboard distance, U, determines the reduction ratio for a given lens; the reduction ratio error is directly proportional to error in U. Thus, a camera that has a positioning accuracy of ± 0.001" will produce no significant error in the reduction ratio.

A.2 Artwork

Dimensional error in artwork is usually caused by coordinatograph positioning error or temperature and humidity variations. The positioning accuracy of a coordinatograph is stated as an interval about the desired point; a typical coordinatograph will have an accuracy of ± 0.001". The total maximum error between two lines cut 0.200" apart is ± 0.002" or ± 1 %.

For maximum dimensional stability the artwork should be cut and photographed at the same temperature and humidity. The room temperature should be regulated to ± 5°F, and the relative humidity should be within ± 10 %. [Maple, 1966, p. 24]

A.3 Step and Repeat Process

The stepped image can be either the final image size or an intermediate size depending on the system used. The registration between masks requires that the stepped images be placed the same interval apart on all masks and that the stepped image is not rotated from mask to mask.

The step tolerance is given in two parts, the step error between adjacent images and the maximum accumulated error in a row or column of images. The maximum error between two masks is twice the maximum error of the step and repeat camera.

The rotational alignment error, Δr, is the maximum displacement error due to rotation of the stepped image. For small angles $\Delta r \simeq r\theta$ where θ is the angle of rotation.

APPENDIX B

EQUIPMENT COMPARISONS

TABLE B-1

COORDINATOGRAPHS

Coordinatograph	Accuracy	Price
Haag-Streit, Model No. A-1 with light table and accessories	± 0.0015	$ 5,424.00
Faul-Coradi (32" X 40") with accessories	± 0.001	5,739.00
Consul and Mutoh, Ltd. Model No. CSL 3232	± 0.001	4,300.00

TABLE B-2

REDUCTION CAMERAS

Reduction Cameras	Artwork Size	Reduction Ratio	Price
HLC, Dekacon I	36" X 36"	4.1 to 7.1 7.1 to 10.1	$ 16,300.00 *
HLC, Dekacon II	40" X 40"	Depends on Lens Purchased	$ 23,065.00 *
HLC, Dekacon III	40" X 40"	Depends on Lens Purchased	$ 23,485.00 *
David Mann, Model No. 1503	40" X 40"	13 to 25	$ 13,900.00 *

* Price includes backlight and one lens

TABLE B-3

STEP AND REPEAT CAMERAS

Step and Repeat Camera	Accuracy	Operation	Resolution	Field Covered	Price
HLC,SAR 45 (Camera Back)	± 0.0005	Manual	-	3.75" x 4.75"	$ 3,495.00
HLC,SAR 810 (Camera Back)	± 0.0005	Manual	-	6.0" x 6.0"	$ 4,950.00
HLC,SAR 810 (Camera Back, Automatic)	± .001"	Automatic	-	6.0" x 6.0"	$ 8,950.00
HLC, Polykon I	± .0002"	Semi-Automatic	20 lines/mm	16" x 20"	$ 17,886.00
Complex 10	± 0.0002"	Manual Auto-indexing	300 lines/mm	2" x 2"	$ 7,920.00 *
Watson Mark III	± 40 x 10^{-6} inches	Manual	-	2" x 2"	$ 9,845.00 *
David Mann, Model No. 1480	± 10 x 10^{-6} inches	Semi-Automatic	650 lines/mm	1.6" x 1.6"	$ 28,100.00 *

* Price includes alignment fixture

TABLE B-4

COMBINATIONS OF REDUCTION CAMERAS AND STEP AND REPEAT CAMERAS

Combined System	Price
David Mann, Model No. 1503 Complex 10	$ 22,120.00
David Mann, Model No. 1503 Watson Mark III	24,045.00
Dekacon I Watson Mark III	26,145.00
Dekacon I SAR 810	21,250.00
Dekacon I Polykon I	34,186.00
David Mann, Model No. 1503 Polykon I	31,786.00
David Mann, Model No. 1503 David Mann, Model No. 1480	42,000.00

TABLE B-5

MASK ALIGNMENT SYSTEM

Mask Alignment System	Price
Kulicke and Soffa Industries, Inc. Model No. 686	$ 8,445.00
Kasper Instruments, Inc. Model No. 17 A	$ 10,900.00
Electroglas, Inc. Model No. 360	$ 5,836.00
Electroglas, Inc. Model No. 500 D	$ 12,280.00

Furnace System

General Configuration

Description	Number
Double chamber diffusion furnace	1
Triple chamber diffusion furnace	2
Water cooling units	3
Gas control cabinets	3
Laminar flow load station	1

TABLE B-6

FURNACE SYSTEM

Furnace System	Price
BTU Engineering Corporation Series: DZ-LH	$ 27,675.00
Electroglas, Inc. Series: Model No. 35	33,505.00
Centigrade System, Inc. Series: 68 Diffusion Furnace	27,681.00
Thermco Products Corporation Series: "Spartan"	26,310.00
Lindberg Hevi-Duty	No Quotation Submitted

APPENDIX C

INITIAL CAMERA DESIGN

The fly's eye camera uses a multiple array lens to produce the finished mask in one exposure. The lens has a resolution of 400 lines/mm and a lens size of 100 mils x 100 mils. The maximum chip size is 90 mils x 90 mils if a 10 mil wide path is left for chip separation. Other lenses are available with lens densities from 100 lenses/in^2 to 4,000 lenses/in^2.

The initial camera design is shown in Figure C-1. The frame is designed with heavy structural steel to prevent vibration and misalignment.

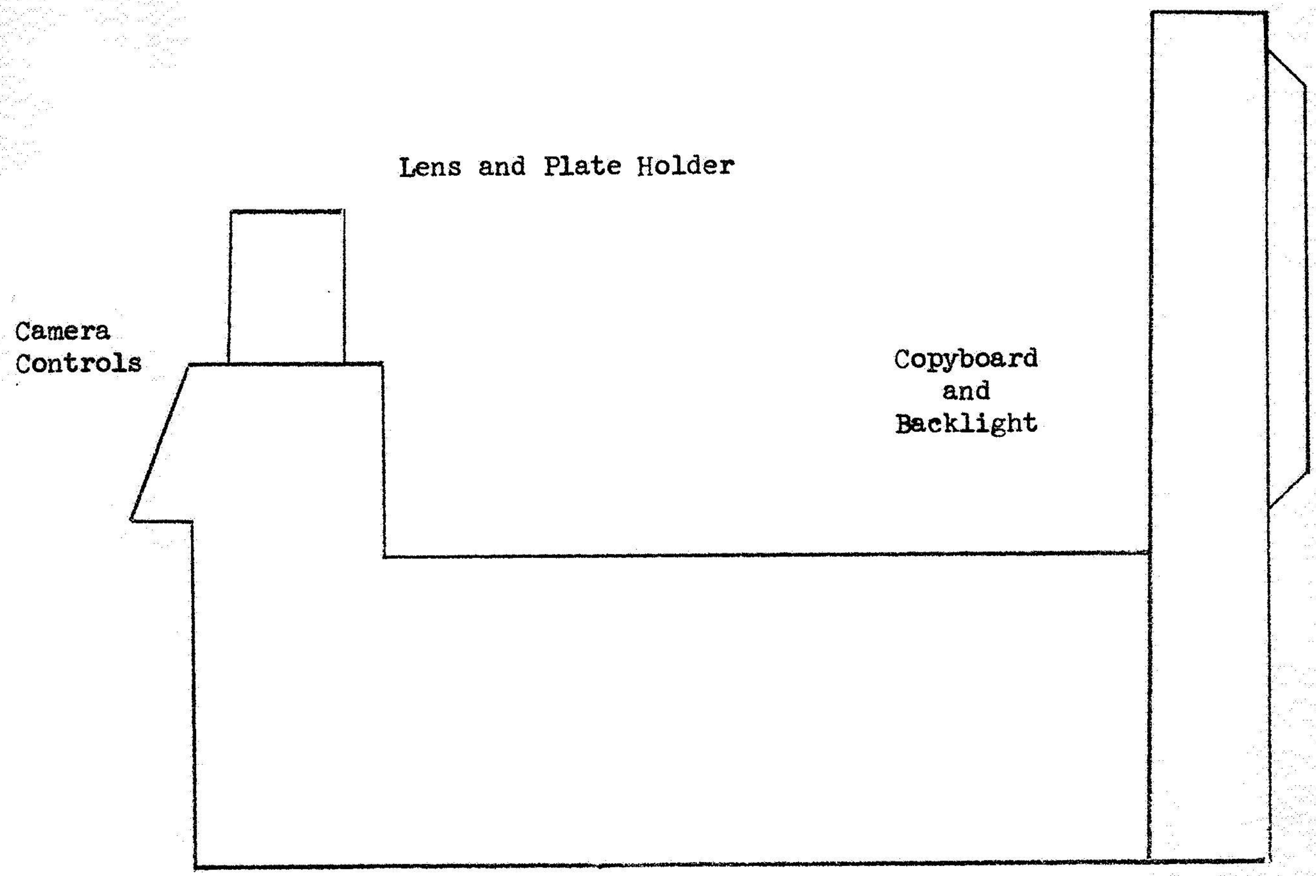

Figure C-1 Initial Camera Design

APPENDIX D

MASK GENERATION COSTS

The cost of mask generation given below does not include the original price of the equipment or additional overhead. The direct price of labor is assumed to be $5.00 per hour.

Artwork

Rubylith, 5 sheets		$ 10.00
Labor, 10 hours		50.00
	TOTAL	$ 60.00

Commercially Made Masks

Artwork (cut at Ames Research Center)		$ 60.00
Five Masks		430.00
	TOTAL	$ 490.00

David Mann Camera System

Artwork		$ 60.00
Plates, high resolution		5.00
Labor, 8 hours		40.00
Materials		5.00
	TOTAL	$ 110.00

Fly's Eye Camera

Artwork		$ 60.00
Plates, high resolution		2.50
Time, 2.5 hours		12.50
Materials		2.50
	TOTAL	$ 77.50

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